Vol. XLII SEPTEMBER, 1923 No. 9

# JOURNAL
## OF THE
# American Institute of Electrical Engineers

PUBLISHED BY THE INSTITUTE
33 WEST 39TH ST • NEW YORK CITY

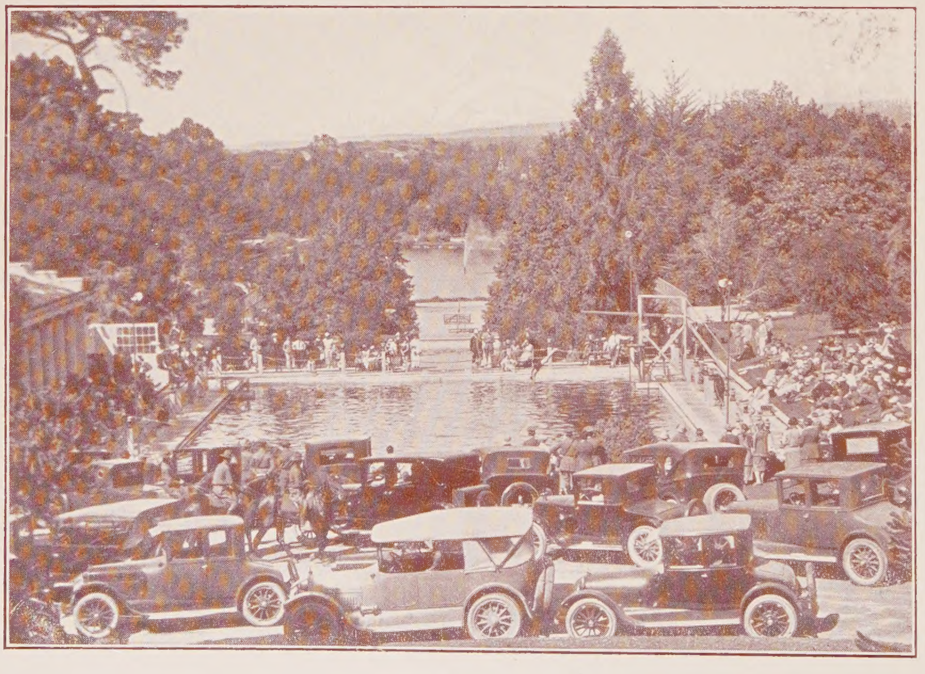
PACIFIC COAST CONVENTION NUMBER

# American Institute of Electrical Engineers

## COMING MEETING

Pacific Coast Convention, Del Monte, Calif., October 2-5

Shaver Lake in the High Sierras, prior to the construction of the power houses of the Southern California Edison Co., on Big Creek and the San Joaquin River.



Open-Air Roman Plunge Hotel Del Monte

# JOURNAL

## OF THE

# American Institute of Electrical Engineers

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 West 39th Street, New York

Subscription. $10.00 per year to United States, Mexico, Cuba, Porto Rico, Hawaii and the Philippines; $10.50 to Canada and $11.00 to all other Countries. Single copies $1.00.

Entered as matter of the second class at the Post Office, New York, N. Y., May 10, 1905, under the Act of Congress, March 3, 1879. Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on August 3, 1918.
Printed in U. S. A.

Vol. XLII SEPTEMBER, 1923 Number 9

## TABLE OF CONTENTS

### Papers, Discussions, Reports, Etc.



### Institute and Related Activities

# Current Electrical Articles Published by Other Societies

---

**Proceedings of Radio Engineers,** August

Interference, by R. H. Marriott

On Super-Regeneration, by E. O. Hulburt

Loop Unidirectional Receiving Circuits for Determination of Direction of Atmospheric Disturbances, by L. W. Austin

Vacuum Tubes as Power Oscillators, by D. C. Prince

**Association of Iron and Steel Electrical Engineers,** August

Practical Installation of Underground Cables, by Philip H. Torchio

**Journal of the American Welding Society,** July

Arc Welded Cast Iron Enamel Ware, by O. H. Eschholz

**Journal of the Western Society of Engineers,** August

The Self-Starting Synchronous Motor and its Application for Power Factor Correction and Industrial Drives, by S. H. Mortensen

**Transactions Illuminating Engineering Society,** July

New Developments in Art Gallery Illumination, by G. T. Kirby and L. X. Champeau

# Insulation Design of Anchors and Tower Supports for 110,000-Volt 4427-Foot Span Over Carquinez Straits

BY L. J. CORBETT

Member, A. I. E. E.

Pacific Gas & Electric Company, San Francisco, Cal.

***Review of the Subject.***—*The first crossing of the Carquinez Straits by a high-tension transmission line was one of the stepping stones in the progress of the electrical industry. The pioneers built well, and the march of events, with its demands for greater and greater blocks of power, found the crossing structure adequate for the new requirements.*

*Constructed in 1901 for one 60,000-volt circuit with a spare cable, two additional cables were added in 1914, making two 60,000-volt circuits. In 1922, coincident with the replacement of 60,000-volt pole lines by a 110,000-volt tower line, the crossing was modified to allow 110,000 volts on the two circuits, thus again practically doubling the transmission capacity.*

*The original design made use of insulating materials in compression. A clear record for over 20 years led the company to adhere to the compression type in the reinsulation for the higher voltage, thus making the crossing unique among long high-voltage spans. The methods by which some of the problems were solved, the hinged anchor structure, the sturdy insulated support for the towers, the movable top for the middle tower support to allow for relative motion and the supplementary cable system to obviate crystallization at the supports, are described in the paper.*

---

When the Bay Counties Power Company installed the 4427-foot span across the Carquinez Strait on San Francisco Bay to operate at 60,000 volts it was considered a noteworthy achievement. So carefully and so thoroughly had all the features been investigated that it established and maintained a record for many years under operation by that company and its successor, the Pacific Gas and Electric Company.

As at first constructed in 1901 there were four cables—one for each phase of the three-phase circuit, and a spare cable. The steel towers were fitted with wooden crossarms supporting saddles of wood and iron upon six pin-type insulators. The anchor insulators, two in series, each consisted of a steel link against micanite in compression in a container filled with oil. These insulators have given complete satisfaction at 60,000 volts for the past 22 years.[1]

In 1914 two additional cables were added, making two circuits at approximately 20-feet separation with cables at 10-feet spacing in each circuit. The crossarms were changed from wood to steel and wood was also eliminated from the saddles. The old anchor insulators were left in but on the two cables added, a steel structure pulling against six pin-type, 60-kv. insulators in compression was installed at each cable end. These have given no trouble whatever since their installation in 1914.

To care for the growth of power load in the San Francisco Bay district and to allow entry for the power from the company's developments on the Pit River, a substation was built about 50 miles northeast of San Francisco where the power is stepped down from 220,000 to 110,000 volts and brought down to the Bay district over new 110,000-volt tower lines replacing the old 60,000-volt pole lines which were no longer adequate. The crossing, mechanically suitable, had to be reinsulated for the new voltage.

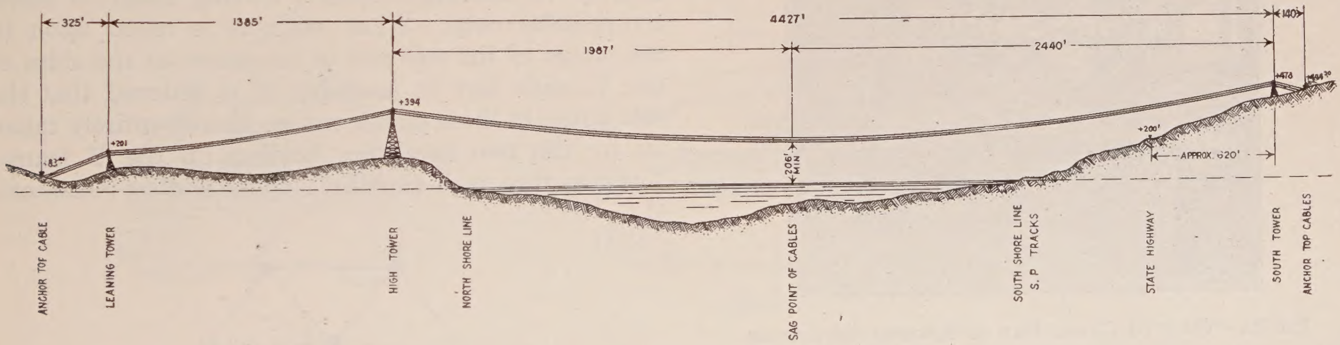



Fig. 1

So successful has the compression type of insulation proved on this crossing that it has been adhered to in the work carried out during 1922, notwithstanding the fact that the tension type of insulation has been developed to a fair degree of reliability and has been adopted on a number of important spans.

Fig. 1 is a profile of the complete cable system. The cables merely rest upon the supports at the three towers, the direct tension being held by concrete anchor blocks at the ends. The South Tower, 140 feet from the extreme anchor block, is 64 feet high to the top crossarm. The Main Tower on the north

---

1. A description of the original installation will be found in the *Engineering News* for October 3, 1901.

*To be presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Cal., October 2-5, 1923.*

side of the straight is 4427 feet from South Tower and is 225 feet high. The North or Leaning Tower is 1385 feet farther on and is 84 feet high. The north anchors extend 325 feet beyond this tower. Due to the differences in elevation of the bases the elevations of the supports of the top cable are 478, 394 and 201 feet on the respective towers. The leaning tower is so called because its upper portion is inclined at an angle of 13 degrees from the vertical in order to resist to best advantage the resultant stress at its location part way down the catenary.

Analysis of the crossing showed that the unequal expansion of the 4427-foot span and the 1385-foot span would cause unbalanced horizontal stresses in the direction of the cable unless provision was made to allow the small amount of relative motion necessary to keep the horizontal stresses on both sides of the tower equal.

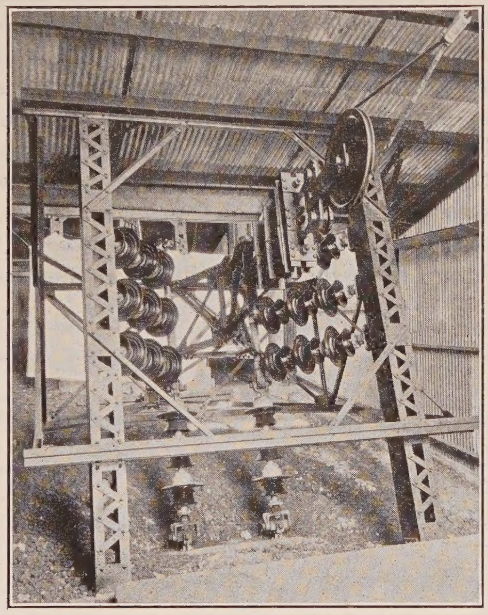


Fig 2A—View of Cable End of Anchor Structure

## Anchors

For the anchors was adopted in part the method used on the cables which were added in 1914. The end of the cable was passed around a 24-inch sheave and securely clamped. From the sheave axle the pull is transmitted through a system of springs to a round bar which forms an axle at the end of the stem of a deep Y-shaped steel frame. The arms of the Y are braced across, and at the extremity of each arm is a round bar which acts as an axle for one end of a set of three pillar insulators on each side. The insulators are inclined outward from the arms of the Y and at their extremities additional axles transmit the strain to two columns which form part of a steel cage which surrounds the insulator system and converges to a point at which it is attached by a hinge to the concrete anchor block. The weight of the Y-shaped frame is supported by two additional pillar insulators with universal joints at top and bottom. Each pillar insulator has a simplified jack at its base by which the strain can be approximately equalized in each set. These features are shown in Figs. 2A and 2B. The anchors are housed in steel and corrugated iron structures affording ample clearances.

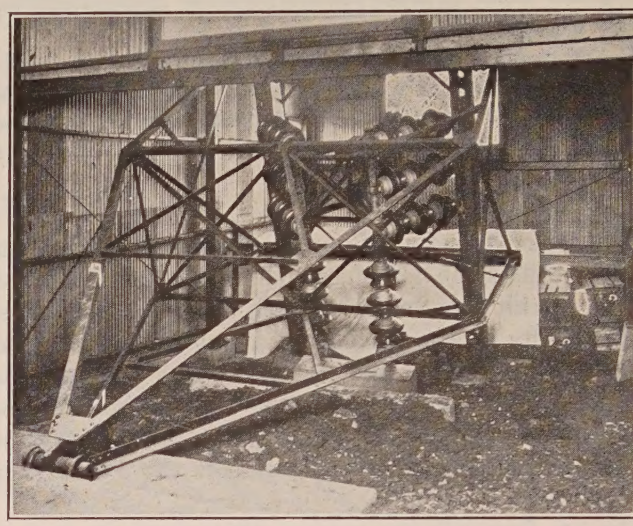


Fig 2B—View of Ground End of Anchor Structure

The aim of the design is to relieve the insulators entirely of bending moment, leaving them to resist compression only. While stiffness is relied upon in the planes of the two sets of insulators at the sides of the Y, with care in assembly it is believed that the side strain in these planes can be almost entirely taken up by the two insulators holding up the Y frame. The structure, including the Y frame and six insulators,

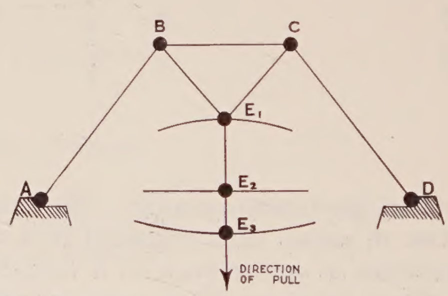



Fig 3—Analysis of Five-Hinged Anchor Structure

rocks into equilibrium on the five hinge bars so that the load is firmly placed on the two sets of insulators.

This five-hinged system was decided upon after analysis and trial of a number of possible arrangements. A rigid rectangular structure, while satisfactory for 60,000-volt insulation with only one insulator in depth, would not serve for 110,000-volt insulation with pillar insulators three times as long, as the side strains would introduce bending moments which it was thought best to avoid, especially since with such a structure, any

yielding to the strain would increase the moment and probably result in complete collapse.

An analysis of the hinged system is shown in Fig. 3. Hinges $A$ and $D$ are fixed in position, while hinges

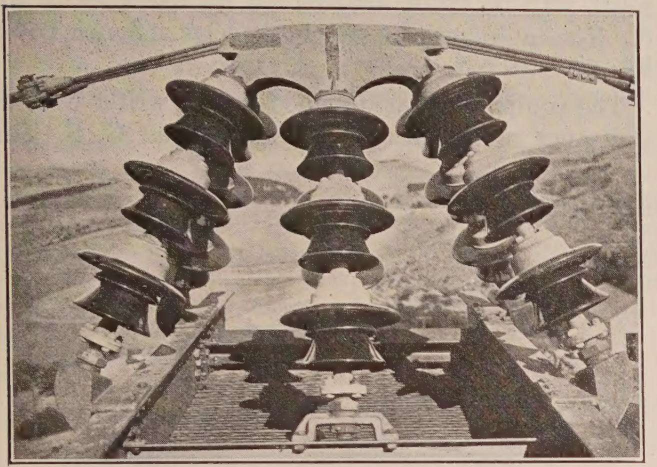


FIG 4—VIEW OF TOWER SUPPORT ON TOWER ADJACENT TO ANCHOR

The saddle is electrically connected to the cable to obviate possible burning at the support.

$B$, $C$ and $E$ are free to shift. The cable is attached at $E_3$.

The location of $E$ along the stem of the $Y$ is extremely important. If the center hinge were set at some point high up on the stem such as $E_1$ where the axis would trace a curve convex upward, any displacement would cause $E$ to run down the curve and the structure would "jacknife" or turn inside out with great rapidity. This was very neatly illustrated by means of a model of a single element made of cardboard in which the pull of the cable was simulated by an elastic string.

Part way down the stem was a point $E_2$ which traced a straight line. Attachment to this point would render the cable indifferent as to its position, judging by the model, and such a structure would of course be unsafe to use where clearances must be maintained on both sides of the cable.

When attached at the position $E_3$ well down the stem of the $Y$ the curve traced is concave upward, therefore the pull of the cable tends to keep it in the center, the low point of the curve. It will be a stable structure even though containing five hinges, and the load will be divided equally between the insulator systems $B$ $A$ and $C$ $D$.

### TOWER SUPPORTS

At each support on the towers a cast steel saddle is mounted on six pillar insulators consisting of three units each, with a jack at the bottom of each pillar to permit equalization of load.

In order to resist side strains caused by wind on the cable and unequal strains in the direction of the line without introducing objectionable bending moments in the insulators, they are mounted in two inclined planes at 22½ deg. from the vertical, and the two outer insulators on each side are inclined at the same angle relative to the center insulator in that plane. (See Fig. 4). The insulators are mounted on cast steel brackets on the 15-inch I beams which form the crossarms of the towers and on two H beams which span between them.

At South Tower and the Leaning Tower, both adjacent to the anchorages, the saddles are stationary and any unequal stresses in the direction of the line will be transmitted to the towers by the rather sturdy insulator structure. These towers are so close to the anchorages, it is believed that such stresses will be very small.

At the high Main Tower, however, with spans of 4427 feet on one side and 1385 feet on the other, unbalanced stresses do result with changes in temperature. For this tower, the saddle is made with a movable top which glides back and forth on rollers, (See Fig. 5). A part of this motion is free, but the last inch in each direction is against buffer springs to transmit any such unbalanced strain to the tower gradually. The rollers are immersed in a thin grease to prevent rust as well as for lubrication. It is found that this motion is freely exercised by the saddle top with daily temperature changes. The limit was approached during construction when a man was sent out in a suspended car to paint the cable, as is the company's practise to do at intervals.

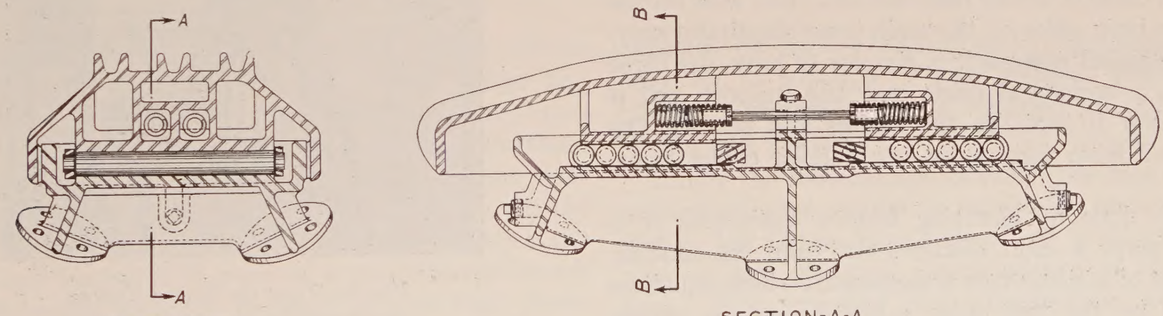



FIG 5—SADDLE WITH MOVABLE TOP

Used on main tower between 4427-ft. and 1385-ft. spans.

### Supplementary Cables Over Tower Supports

The cables on the long spans are subject to serious vibration which in time would cause crystallization of the steel at the tower supports unless precautionary measures are taken. This vibration changes with the velocity of the wind and is of two types,—one is evidenced by a continuous hum, the other is in the nature of an impulse which travels back and forth across the span at intervals of a few seconds. To afford cushioning for these vibrations at the tower supports and to add to the strength at these important locations, supplementary cables are used over the saddles. By thus adding to the weight of the main cable before it reaches a support, the vibration is absorbed gradually and its concentration at one point is avoided. Two supplementary cables of the same size and quality as the main cable are used at each tower support and arranged with turnbuckles so that all or part of the tension can be taken off the main cable.

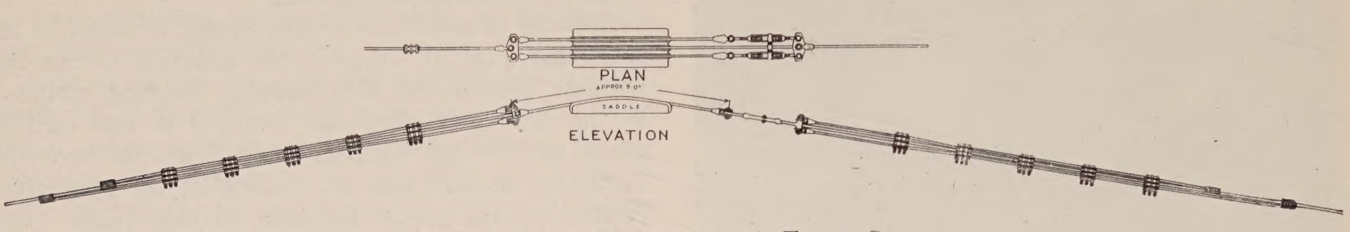



Fig 6—Supplementary Cables over Tower Supports

As the wind alternates from sea breeze to land breeze, the main cable is swung first east and then west on the spans on both sides of the main tower simultaneously. For mechanical reasons it is simpler to have the three cables in a horizontal plane over the support, but it is necessary to equalize the strains and prevent the entire pull from coming on the outside cables alternately.

This is done by changing from a horizontal to a vertical plane a short distance out from the saddles, by means of a single-tree arrangement which equalizes the load on the two outer cables across the saddle and permits the main cable in the center to go free.

The supplementary cables across the saddles are short sections with sockets on both ends. The turnbuckles are joined to these portions for tightening as much as desired to equalize the load and relieve the main cable of a part or all of the strain. These short sections and turnbuckles go between the equalizing plates at their outer holes at each end, the main cable passing through between the plates. The center holes of the plates engage pins in open sockets on the ends of cables which parallel the main cable in a *vertical* plane. These cables are also of the same character as the main cable and are attached to it and to each other by five clamps which hold all three cables at suitable spacing. The ends of the supplementary cables beyond the clamps are attached to the main cable by serving or Crosby clips, the lengths being varied on the different spans to provide suitable cushioning for the vibration. The distances to which the cable ends extend vary from 21 to 55 feet from the centers of the towers, one cable however being terminated at a lesser distance in each case. The arrangement may be better understood by reference to Fig. 6. The cables may be seen in the view of South Tower, Fig. 7.

The equipment was designed by the writer with the assistance of Messrs. A. T. Church and G. S. Tune of the drafting room staff and under the supervision of Mr. J. P. Jollyman, chief of the division of hydroelectric and transmission engineering for the company.

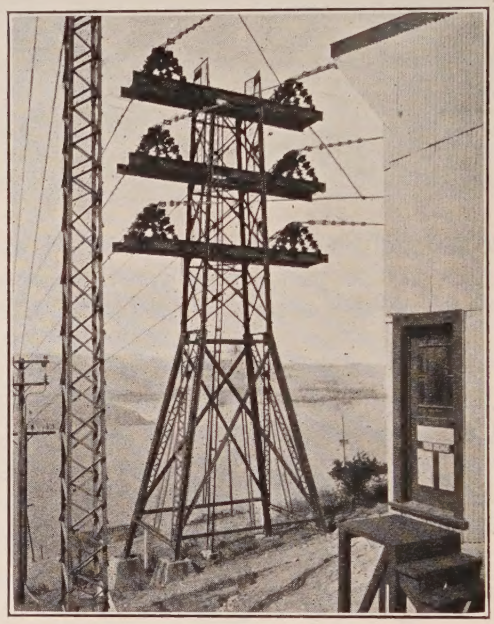


Fig 7—View of South Tower
Note supplementary cables and clamps

## TESTS OF RADIO RECEIVING SETS

The results of tests of radio receiving sets by the Bureau of Standards are given in a series of Letter Circulars of which the first (No. 90) dealt with tests of electron tube sets. The second circular of this series (No. 93) is now ready for distribution and gives the results of tests on crystal detector sets.

It is believed that the methods followed and the examples given in these reports will be of assistance to manufacturers in the development of methods of testing besides aiding them to properly describe and improve their products.

# 110-Kv. Transmission Line for Oak Grove Development of Portland Railway, Light and Power Company

BY H. R. WAKEMAN and W. H. LINES
Member, A. I. E. E.
Both of The Portland Railway & Light Co.

***Review of the Subject.**—This paper covers the design of the 110-kv. transmission line to transmit energy from the new Oak Grove development of the Portland Railway, Light and Power Company to the city of Portland, Oregon, a distance of 54 miles.*

*The company now has three hydroelectric developments aggregating 52,000 kw. supplied from the same general watershed from which energy is transmitted to Portland over five 60-kv. circuits, only one of which is on steel towers. The problem was to design a transmission line to most economically handle the three 30,000-kv-a. units as installed at the new development and to tie in with the existing transmission system. The following factors were considered in determining the design:*

1. *Transmission voltage*
2. *Conductor capacity*
3. *Maximum conductor tension*
4. *Assumed maximum mechanical loading conditions*
5. *Type of supporting structures*

*Consideration was also given to the physical characteristics of the country through which the line must be built. For 14.8 miles the line will be located in the United States Government Forest Reserve, which is very heavily timbered, and accordingly cost of clearing will be very high, averaging $15,000 a mile, even after credit for merchantable timber is allowed. This fact, outside of other considerations, required a minimum number of circuits. To reduce clearing costs as much as possible, the line was located along the river gorge necessitating 55 angles, a few as great as 60 deg., and 28 river crossing spans, vearying from 400 to 1800 feet.*

*After considering various types of supporting structures, three types of double circuit, heavy rigid steel towers were decided upon as follows:*

*Type A towers, to be used on tangents up to 800-foot spans, also on curves up to 10 deg., the spans not exceeding 500 feet; suspension insulators to be used.*

*Type B towers, to be used on tangents up to 1700-foot spans, also on curves from 8 to 30 deg., the spans not exceeding 800 feet for the larger curves; suspension insulators to be used.*

*Type C towers, to be used at dead-ends and curves over 30 deg.*

*Towers are designed for 250,000, cir. mil. copper conductors, and maximum loading conditions of one-half inch of ice and eight pounds per square foot wind pressure at 0 deg. fahr. were assumed. Each type of tower was designed to withstand the maximum loading conditions plus 50 per cent without exceeding the elastic limit of the steel, and the towers were subjected to an actual field test. Special steel having an elastic limit of 45,000 pounds per square inch and a minimum elongation of 22 per cent was used in the towers.*

*In order to reduce the number of insulators and deadend positions, use was made of brackets pivoted to the cross arms so that they would be free to swing in the line but rigid across the line.*

*12-inch brackets are provided for the Type A towers on 8 deg. curves and 24-inch brackets on Type B towers with 30 deg. curves so as to maintain a three-foot clearance between the conductor and steel on that side of the tower where the conductors pull the insulator strings up and toward the cage. The use of these brackes reduced the total cost of the insulators and hardware fully 25 per cent.*

*Tables are included giving resultant simultaneous loading and weights and dimensions for each type of tower.*

---

THIS paper is one of several dealing with the review of the problems encountered in the design and construction of the high-tension tower lines completed during the past two years. The Portland Railway, Light and Power Company has not constructed any lines of importance in this class during the period in question, but has recently completed the design and started field work on a transmission circuit of considerable capacity to serve its new Oak Grove development. This project is situated on the Clackamas River, a tributary of the Willamette, about 54 miles from the city of Portland. The ultimate capacity of 90,000 kv-a. will be provided by three units of 30,000 kv-a. each, the first of which is scheduled for completion in September, 1924, the others to follow as the system load requires.

At the present time the company has three hydroelectric developments, aggregating 52,000 kw. in capacity, fed from the same general watershed, two of which are located on the Clackamas River, 19 and 22 miles respectively below the Oak Grove development, and one on the Bull Run River, a tributary of the Columbia. Transmission from these plants is supplied by five circuits at 60 kv. grounded neutral, only one of which is on steel towers. Four of these circuits converge at Lents Junction on the outskirts of the city proper.

Briefly the problem was to design the most economical transmission system to handle the successive units of the Oak Grove development and to tie in with the physical and electrical characteristics of the present lines. This involved the consideration and proper economic selection of the following major variables:

1. Transmission voltage.
2. Conductor capacity.
3. Maximum conductor tension.
4. Assumed maximum mechanical loading conditions.
5. Type of supporting structures.

Naturally all of these variables are intimately related and in addition are effected by the physical conditions obtaining along the line. To arrive at the proper economic solution due consideration was given all the physical conditions and all possible combinations of the five major variables mentioned above.

The first step was a reconnaissance and a preliminary location of the line in the field. Then a party was organized and a sufficient topography taken to enable

---

*To be presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Cal., October 2-5, 1923.*

the selection of the best profile. The data thus obtained brought out the following physical facts affecting the design:

The total length from generating station to Lents Junction, where it is proposed to tie with existing 60-kv. circuits, is 45 miles. Of this distance 14.8 miles is in U. S. Government forest reserve and very heavily timbered. In order to secure a right-of-way from the Forest Service, the company was forced to agree to several somewhat stringent regulations as to the methods to be used in felling timber and clearing up, and these requirements, plus the price paid for stumpage, will result in an average cost of about $15,000 per mile to clear and clean up a 400-foot strip through the reserve, even after proper credits are allowed for merchantable timber, which it is proposed to market. In order to avoid as much as possible all this excessive cost, the line was located along the river gorge, which, in turn, required many horizontal angles and river crossings. In addition, it became apparent that a minimum number of circuits should be adopted in order to avoid excessive clearing costs. In the upper 19 miles of the line, namely, from the generating station to Faraday, at which point existing transmission circuits start, there are 55 angles, a few of which are as great as 60 deg., 28 river crossings with spans varying from 400 to 1800 feet, and numerous grades, some over 75 per cent.

### Transmission Voltage and Capacity

It was determined, after proper consideration of the above physical facts, that for the ultimate development of 90,000 kv-a. two circuits each of 250,000 circular mil hard-drawn, stranded copper, at 110 kv. grounded neutral, were respectively the economic number, size and voltage to employ.

### Maximum Conductor Tension

This was a problem to which considerable study was given. The limitations imposed by the mechanical strength of available insulators and hardware were a considerable factor in the decision to use 4000 pounds maximum conductor tension, equivalent to a stress of 20,000 per square inch or one-third of the ultimate strength of the conductors in this line.

### Assumed Maximum Loading Conditions

After an investigation of the possible sleet, snow and wind conditions in the country traversed by this line, it was determined to use class B loading, namely, a maximum conductor tension equivalent to the load of the conductors plus one-half inch of ice and 8 pounds per square foot wind pressure on the ice-coated conductors at temperature of 0 deg. fahr.

### Type of Supporting Structures

Before a decision was reached on this point, there were placed on the profile, to scale and by means of properly constructed sag templates, four types of supporting structures designed for the assumed loading conditions and appropriate for the physical topography of the country. Thomas sag curves were used in computing the relations between stress and sag under various loading conditions. It was found that the maximum sag occurred on the line under summer loading conditions, at a temperature of 120 deg. fahr. The following are the four types of supporting structures which were considered:

1. Single wooden poles, average spans 300 feet, single-circuit capacity.
2. Double wooden poles (H frames), average spans 450 feet, single-circuit capacity.
3. Light steel towers (combination of flexible frames and anchor towers), average spans 500 feet, double-circuit capacity.
4. Heavy rigid towers, average spans 700 feet, double-circuit capacity.

Detailed estimates of material and labor were then prepared for each of the four types and these resulted in favor of the fourth, namely, heavy rigid towers, average spans 700 feet.

A brief consideration of the following points will perhaps explain this result:

The cost, coupled with the possibility of failure of modern high-voltage insulators and hardware, tended to force the adoption of longer spans and thus fewer insulators. In the case of wooden poles, the item of hole digging for poles and guy stubes, mostly in rock, was considerable. Guying costs to reinforce pole strength at the many horizontal and vertical angles in the line were excessive. River crossing and other spans of greater than the average length required the adoption of special and expensive structures to provide the required strength. The difficulty of placing material along the line was also a considerable factor in making the estimates high, particularly with the wooden pole structures with their attendant extra weight per mile of line.

From a study of the loading conditions imposed on the towers by the varying span lengths and the horizontal and vertical curves, it was decided to provide three types of towers to meet all these loading conditions, as follows:

*Type A Towers.* To be used on tangents up to 800-ft. spans, also on curves up to 10 deg. with spans not exceeding 500 feet; suspension insulators to be used.

*Type B Towers.* To be used on tangents up to 1700-foot spans, also on curves from 8 deg. to 30 deg. with spans not exceeding 800 feet for the larger curves; suspension insulators to be used.

*Type C Towers.* To be used at dead-ends and curves over 30 deg.

The towers were designed to withstand maximum loading conditions embraced in each of the above classes, plus 50 per cent as an assumed margin of safety, without exceeding the elastic limit of the steel. In Types A and B, where suspension insulators are

used, consideration was given the fact that with a broken conductor on one side of the tower the insulator string will swing into the line, increasing the sag, and thus reducing the conductor tension and tower loading. At all horizontal angles the towers will be set to bisect the line angle.

Following is a summary of the resultant simultaneous loading assumed for each type of structure and applied at points of insulator support:

| Loading Conditions | Type A | Type B | Type C |
|---|---|---|---|
| Number of conductors assumed broken | 3 | 6 | 6 |
| Maximum horizontal curve | 10 deg. | 30 deg. | 60 deg. |
| Maximum span length when combined with curve | 500 | 800 | 800 |
| Vertical load—dead weights of conductor | 6 at 1,800# | 6 at 1,200# | 6 at 1,200# |
| Horizontal load in line component of conductor tension | 3 at 4,000 | 6 at 3,500 | 6 at 5,200 |
| Horizontal load across line component of conductor tension + wind on cond. | 6 at 1,400 | 6 at 2,200 | 6 at 3,700 |
| Horizontal load across line wind on tower | 1 at 1,600 | 1 at 1,600 | 1 at 1,600 |
| | 32,800# | 43,000# | 62,000# |

The type A tower on tangents will accommodate spans to 800 feet.
The type B tower on tangents will accommodate spans to 2400 feet.

The design of the towers was also checked for maximum possible torsional load, namely, with three conductors broken on one side of the cage.

Special steel having a guaranteed elastic limit of 45,000 pounds per square inch and a minimum elongation of 22 per cent was used in the towers. Actual tests of samples taken from the tower stock showed yield points from 48,000 to 53,000 pounds per square inch.

As a positive check on the design, each type of tower was subjected to an actual field test, and all of them withstood the prescribed loads without permanent deflection of any member. We are reliably informed that these towers are the lightest ever built for equivalent loading conditions, which fact can be explained in part by accurate design and in part by the use of high elastic limit steel. The following tabulation of comparative dimensions and weights may be of interest:

In order to eliminate any possibilities of the conductors at different elevations swinging together when a lower conductor drops a heavy ice load before the one above, the middle conductors were offset two feet beyond the top and bottom ones.

Steel footings were decided upon on account of the difficulty and expense of handling and mixing concrete along the line. The footings are designed to resist maximum uplift 10 per cent greater than that occasioned by the assumed test loading conditions.

The towers are designed to permit hillside and square extensions at 5, 10, 15 and 20-foot intervals and any

| | Type A | Type B | Type C |
|---|---|---|---|
| Cage | 4 ft.-6 in. | 4 ft.-6 in. | 4 ft.-6 in. |
| Length of crossarm, cage to insulator support | 7 ft.-0 in. & 9 ft.-0 in. | 7 ft.-3 in. & 9 ft.-3 in. | 7 ft.-3 in. & 9 ft.-3 in. |
| Horizontal separation of conductor at supports | 18 ft.-6 in. & 22 ft.-6 in. | 18 ft.-9 in. & 22 ft.-9 in. | 18 ft.-9 in. & 22 ft.-9 in. |
| Vertical separation of conductor at supports | 10 ft. | 10 ft. | 10 ft. |
| Height of lowest arm above ground | 48 ft. | 48 ft. | 45 ft. |
| Overall height above ground | 72 ft. | 72 ft. | 69 ft. |
| Weight of tower exclusive of extension and footings | 4325 # | 5355 # | 5635 # |
| Weight of footings (all steel) | 550 # | 1820 # | 2780 # |
| Depth of footings in ground | 7 ft.-6 in. | 6 ft.-6 in. | 7 ft.-6 in. |
| Area of footing at bottom | 3 ft. x 3 ft. | 4 ft.-8 in. x 4 ft.-8 in. | 5 ft.-6 in. x 5 ft.-6 in. |

combinations of these. Some idea of the nature of the country can be had when notice is taken of the fact that approximately 70 per cent of all the towers in this line are provided with an extension of some sort.

A maximum clearance, conductor to steel, of 3 ft. 0 in. was specified for all possible positions of the conductor.

An interesting detail in connection with this line was the decision to employ a string of insulators in suspension position on horizontal curves up to 30 deg. In order to maintain the specified clearance of 3 ft. conductor to crossarm, it became necessary to drop the point of insulator support 12 in. on Type A towers (8 deg. curve) and 24 in. on Type B towers (30 deg. curve) below the crossarm on that side of the cage where the conductor pulls the insulator string up and toward the cage. This was accomplished by the use of brackets attached and pivoted to the crossarms so that they would be free to swing in the line but rigid across the line. The use of this device saved fully 25 per cent of the total cost of insulators and hardware and further reduced the number of actual dead-end positions, always a possible source of insulator failure, to a minimum.

Insulators are attached to crossarms by means of forged steel hooks with an elastic limit of 6000 pounds. It was thought best to limit the strength of this connecting member so that if any load greater than the assumed came on the conductors, the connection would fail rather than the tower.

The two transmission circuits above described were designed to transmit the ultimate development of Oak Grove, 90,000 kv-a., at 110 kv., a distance of 45 miles to Lents Junction where it is planned to tie them through auto-transformers on to a 60-kv. switching bus. The existing 60-kv. circuits from other hydroelectric plants will tie on to the same bus. Two synchronous condensers of 15,000 kv-a., each supplied by tertiary windings from the auto-transformers, are planned at this point for power factor correction and voltage regulation of all incoming lines.

# Waterwheel Generators and Synchronous Condensers for Long Transmission Lines

BY M. W. SMITH
Associate, A. I. E. E.
Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

***Review of the Subject.***—*It is the intention of this paper to bring out some of the special conditions which affect the operation and design of machinery for long transmission lines and the discussion is confined largely to waterwheel generators and synchronous condensers.*

*Under the subject of generators, the following points are discussed: Leading current drawn by transmission lines and its effect upon the stability and mechanical design of generators; characteristic curves of generators designed for operation at leading power factor; special winding connections which increase the capacity of generators for leading power factor operation for temporary periods without increasing their weight and cost; description of general construction and ventilation of a 28,000-kv-a. vertical waterwheel generator.*

*The following points are discussion with reference to synchronous condensers: Operation at leading and lagging power factor and how it affects the stability cost and weight of the machines; special winding connections and their effect on stability; general mechanical construction with particular reference to damper winding design and the use of sheet steel end bells; the importance of losses and a curve showing values it is possible to obtain on machines with the latest improvements in design; starting kv-a. and how it may be minimized by the use of oil pressure in the bearings.*

CONTENTS



WHILE the design of waterwheel-driven generators and synchronous condensers for long transmission lines is, in general, the same as for other applications, there are often special conditions imposed on machinery for long transmission lines which make the design special and of greater cost and, in the case of large high speed units, often difficult. A better knowledge of these operating and design difficulties by both operating and designing engineers might enable them to modify the conditions in such a manner as to obtain a lower cost and better operating installation as a whole. Some of the special conditions applying to the design of machinery for long transmission systems are discussed in this paper with this idea in view.

## Leading Current and Stability of Generators

The effect of the leading current taken by a long transmission line upon a generator is shown by curves in Fig. 1. Curves 1, 2 and 3 represent the saturation curves for no-load, full-load, 0 per cent power factor lag and full-load 0 per cent power factor lead, respectively. The shape of curve 3 below the point *c* is of little practical value and is out of the range of practical operation. Assuming that an external power factor of 0 per cent lead could be maintained and no losses in the circuit the curve 3 would extend down to the point *e* and have a shape similar to curve 2. This assumption, of course, never exists. It would mean condenser capacity approaching infinity and no resistance. In actual practise the resistance and losses in the circuit would tend to give curve 3 a shape indicated by *a d f*. However, this means that the machine must produce torque and that its power factor is not 0. With such low excitation as indicated by the point *d*

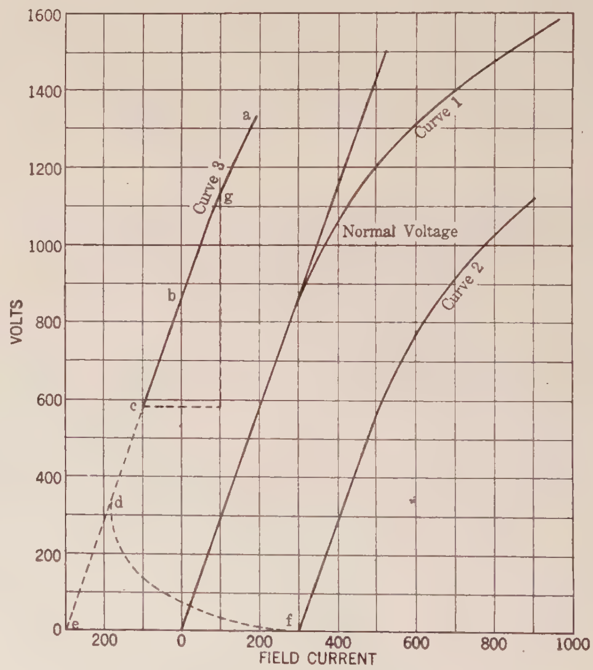



FIG. 1—REPRESENTATIVE SATURATION CURVES

even a salient pole generator cannot supply the required torque for the losses of the machine and line and will "slip a pole" or "pull out". Therefore, in practical operation curve 3 cannot follow either the shape *a d e* or *a d f* below some point such as *c*. If in practise

*To be presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Cal., October 2-5, 1923.*

it is attempted to operate the machine on curve 3 below point $c$, the generator will slip a pole as stated above and the excitation which was negative will become positive with respect to the voltage on transmission line (since it is reversed) and the voltage will rise from the value $c$ to the value $g$. This, of course, is a dangerous condition and care must be taken in the design of generators which must supply high values of leading current to prevent the necessity of the field excitation being reduced to such low values that the generators will not have sufficient synchronizing power or stability. It is not considered good practise to go below zero excitation even on salient pole machines where the irregularity of the magnetic circuit permits the development of torque even at reversed excitation. On machines with uniform reluctance of the magnetic circuit in the rotor, such as steam turbine generators, stable operation cannot be had at any reversed field excitation. The term "stability" is rather general, but it is used here to refer to the ability of synchronous apparatus to remain in synchronism without hunting or pulling out of step.

### Effect on Mechanical Design

To increase the stability of generators, supplying leading current the field, strength must be increased with respect to that of the armature. In other words, the design of the machine must be such that the effect of the leading current in the armature on the field will be minimized. This means increasing the ampere-turns on the field or decreasing the ampere-turns on the armature or a combination of both. Any of these methods results in a heavier and higher cost machine than normal, but the latter procedure or method is usually more economical. Not only is the weight and size of the machine increased as a whole, but the rotor parts become abnormally large in proportion to the whole machine. This means a more expensive rotor construction to withstand the high stresses encountered at the overspeed condition. On large high speed units this may become quite serious. After the limit of axial length as determined by ventilation has been reached, the only other alternative to meet abnormal line charging conditions is to increase the diameter and hence peripheral speed. Therefore, it is evident that special line charging conditions may become a limiting feature in the mechanical as well as in the electrical design.

Difficult conditions of this nature were met in the design of three large high-speed generators recently built for the Southern California Edison Company. So far as the writer knows, these generators are the largest waterwheel machines ever built to run at so high a speed. They have 50-cycle ratings of 28,000 kv-a. and 33,500 kv-a. at guaranteed temperature rises (by detector) of 60 deg. cent. and 90 deg. cent., respectively, at 428 rev. per min., and they have 60-cycle ratings of 31,300 kv-a. and 37,500 kv-a. at guaranteed temperature rises of 60 deg. cent. and 90 deg. cent. respectively at 514 rev. per min. They are required to meet an overspeed of 85 per cent at either frequency. At the 60-cycle overspeed (951 rev. per min.) the peripheral speed of the rotor is nearly 28,000 feet, or over 5 miles per minute. This is unusually high for a salient pole machine (although quite common in cylindrical

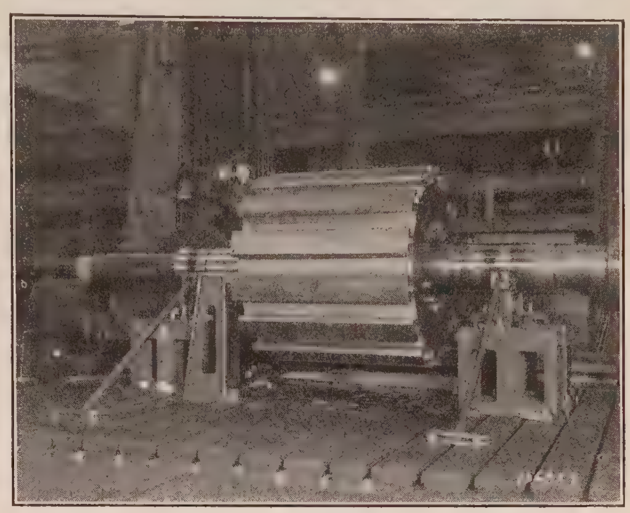


Fig. 2—Plate Spider for 28,000 Kv-a. Vertical Waterwheel Generator

rotors of steam turbine driven generators) and a very careful design of the pole and spider proportions was necessary in order to equalize the rotor stresses and work the material in the most effective manner. The rotor spider is built of rolled steel plates, approxi-

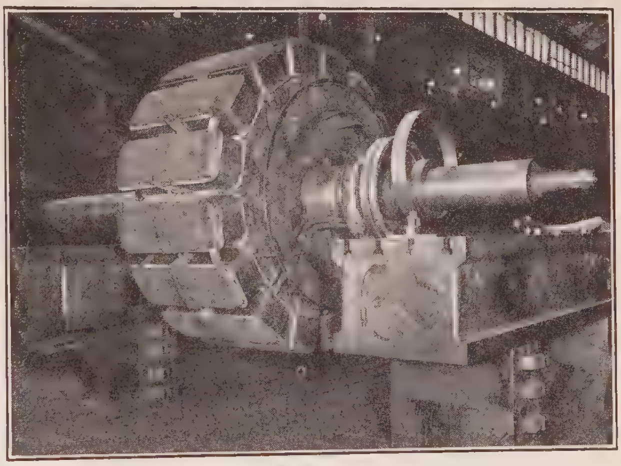


Fig. 3—Rotor of 8125 Kv-a. 6600-Volt, 50-Cycle, 600-rev. per Min. Waterwheel Generator

mately 2½ inches thick carried on a through shaft. A photograph of the spider is shown in Fig. 2. The poles are built of 1/16-inch rolled steel punchings which are riveted and bolted together between cast steel end plates. This built-up construction of the rotor spider insures material with uniformity and reliability which is unquestioned. The construction

of the rotor is similar to that shown in Fig. 3, except that two coil braces were necessary between poles on account of the high speed and great length of the field poles and coils.

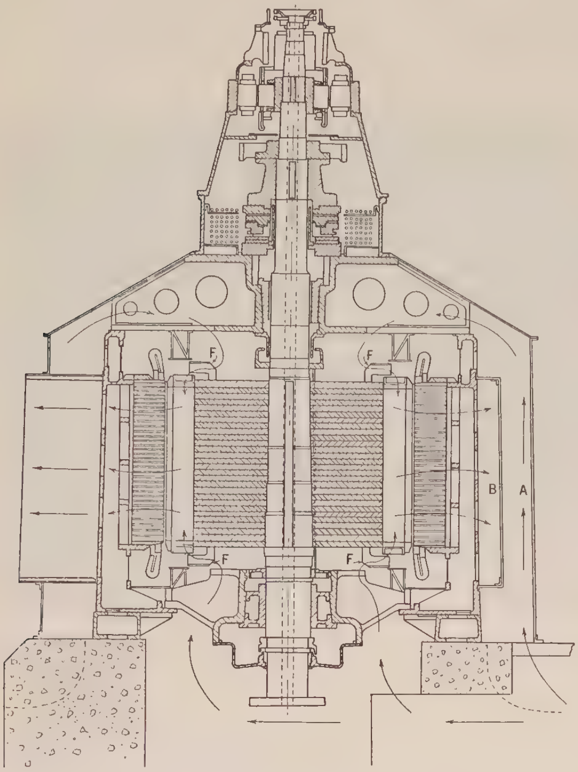



Fig. 4

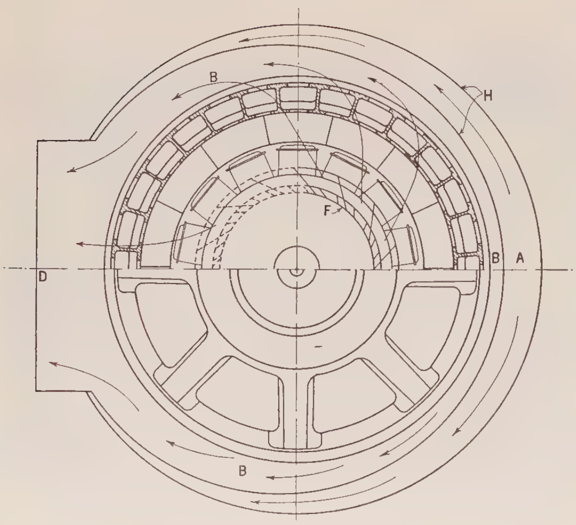



Fig. 4a

The field coils are made of copper strap formed on edge. The bulge or swell at the corners caused by the bending process was pressed out by means of a hydraulic press. In this operation steel plates were placed between turns as shown in Fig. 5 to prevent the skewing of the coils. After being smoothed up by filing where necessary the individual turns were thoroughly coated with an air drying shellac and permitted to dry. Two insulating strips of asbestos each coated on one side with shellac were then placed between turns and the coil heated to near a red heat (by circulating current) in order to drive out all solvent and volatile matter. During this process the coil was held in shape by heavy metal sizing plates, pressed to size and allowed to cool. Particular attention was paid to the cell insulation between the coil and pole. It is made of several thicknesses of 10-mil flexible and hand built mica

Fig. 5—Pressing Out the Swell or Bulge at the Corners of a Strap Field Coil

Fig. 5a—Assembling of Coil Insulation on Strap Wound Field Coil

sheets. These sheets were cut wide enough to cover the inside of the coil and to be turned down over the top and bottom edges as shown in Fig. 5a. The mica is the darker material extending above the coil and is reinforced all around by one thickness of heavy asbestos cloth which is indicated by the light portion of the material extending above the coil. Both the asbestos cloth and mica are turned down over the top and bottom edges of the coil, but the

asbestos cloth was made sufficiently long to be turned back under and between the mica and the top and bottom of the coil. The cell was then given a heavy coat of bakelite and moulded to the coil while heated and held in place under pressure with metal plates. In this process the bakelite becomes hard and forms a solid moulded insulation around the coil. Furthermore, with the asbestos cloth turned back under the ends of the mica cell no raw edges are exposed. When the coils were assembled on the poles they were further protected by micarta washers at the top and bottom.

The drawings in Figs. 4 and 4A show a cross-section and plan view of the machine with exciter and Kingsbury thrust bearing, and a photograph of one unit without the air housing is shown in Fig. 6. The general construction of the machine is of conventional

Fig. 6—28,000 Kv-a., 11,000-Volt, 3-Phase, 50-60 Cycle, 428-514 Rev. per Min. Vertical Waterwheel Generator

design. The lower guide-bearing bracket is insulated from the generator frame to prevent the circulation of bearing currents through the guide and thrust bearings. The lower end plate, supporting the lower finger and core punchings, is cast integral with the frame. This construction facilitates building and pressing the core.

It was necessary that all the cooling air (for both top and bottom of the machine) be brought in at the base of the generator. On low-speed machines which permit the use of open-type spiders through which the air for the upper part of the generators may be drawn,—this condition causes no difficulty. However, on machines such as these where the size of the rotor and the stresses make it advisable to use a solid plate construction, the cooling air obviously cannot be brought up through the rotating part. A special air housing as indicated in Figs. 4 and 4A has been used in this case for conveying the cooling air to the top of the machine and for collecting and discharging the hot air from the frame. The upper part of the housing is attached to and has the same slope as the upper bracket arms. Although the individual chambers of the air housing are eccentric with respect to the generator, the outer contour is circular (except where the outer discharge duct is attached at *D*) and concentric with the generator. This gives a symmetrical appearance and does not detract from the appearance of the machine. The cooling air for the bottom half of the the unit is drawn directly from the pit, while the air for the top half is drawn in at openings in the floor up through chamber *A* and discharged into the opening or chamber between bracket arms. Holes are provided in the webs of the bracket arms through which any unequal discharge of air into this space between arms can be equalized. The air goes directly into the machine through the fans from this chamber. The air from both the top and bottom of the machine, is then forced through the vent ducts in the core and out the holes in the frame to the discharge chamber *B* and thence through the discharge *D* to the outside of the building through ducts.

### Characteristic Curves

Two of these generators were completely assembled and set up for tests in the factory, and are about the largest units ever to receive a complete factory test. With two units assembled, it was possible to obtain temperature tests at normal voltage current and frequency at 0 per cent power factor by over-exciting one machine and under-exciting the other, the losses being supplied from the factory testing equipment. The temperature rise on the stator of the over-excited unit was within 45 deg. cent., by either of the three methods of measurement as defined by the A. I. E. E. Rules. Complete segregated losses and characteristic curves were also taken.

The characteristic no-load and load saturation curves obtained from these tests are shown in Fig. 7. These generators were designed to carry 1680 amperes at 0 per cent power factor leading and 8910 volts at 50 cycles without becoming self-excited. This is 14 per cent more than the normal current of 1470 amperes and 81 per cent of the normal voltage of 11,000. They were also designed so that with a constant separate d-c. excitation corresponding to 2000 volts no-load, they would not be self-exciting above 8910 volts when delivering 1400 amperes 0 per cent power factor leading. Both of these conditions are unusually severe. Curve 3 shows the former condition and curve 5 the latter, and it may be seen from these curves that both conditions were met with a reasonable margin. The condition shown by curve 5 is the more severe and is, of course, the determining one.

If the generator had to operate at leading power factor only, it would be quite easy to make the machine stable without exceeding normal costs and weights. However, it is the lagging power factor operation that imposes the severe condition when the machine is especially proportioned for leading power factor conditions. It can readily be seen from the curves in Fig. 7 that anything that is done to make the leading power factor operation more stable, such as increasing the air gap or the normal induction and saturation,

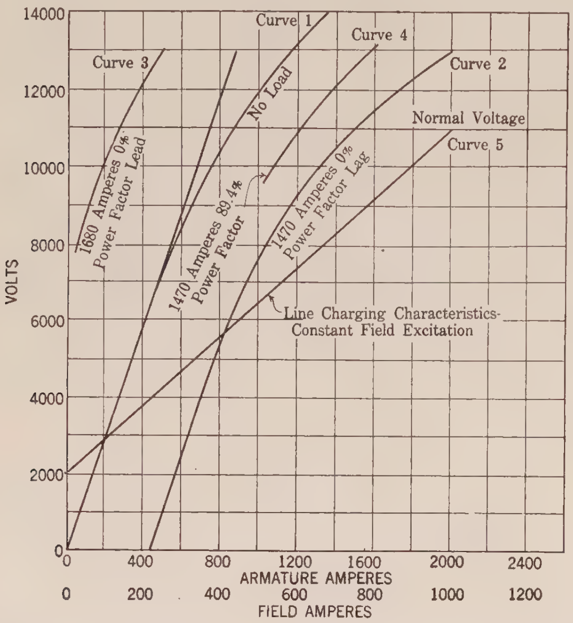



Fig. 7—Test Curves on 28,000-Kv-a., 11,000-Volt, 3-Phase 50-Cycle, Vertical Waterwheel Generator

will increase the demand on the field winding at lagging power factor operation. This means an increase in the field temperature, or an increase in the field copper, or an increase in the size of the machine, or a combination of these.

## Special Conditions and Winding Connections

Ordinarily, the leading power factor operation is encountered only at short and infrequent intervals when a transmission line is unloaded and the power factor becomes lagging when the load is on. However, in the case of a line built for a large ultimate load but that has a small initial load and generating capacity the power factor even at maximum kw. load of the generator may be leading. This means that the generator must be designed for a very stable operation at leading power factor and must also be able to take care of the lagging power factor operation in the future when the ultimate load builds up on the line. For the machine to deliver power under leading power operation requires that it be designed with more stability than when merely charging the line to insure that it will not pull out of step on account of the torque it must develop. Therefore, a unit for this class of service may become unduly large and expensive. In cases like this the use of a machine of normal design with some special connection of the armature winding, such as an inter-connected star, during the period of light load on the line is suggested. In this scheme, each leg of the ordinary star winding is opened at the mid-point and each half of each leg is connected in series with half of another leg which has a phase relation of 120 degrees with respect to it. Diagrams of this connection are shown in Fig. 8. Diagram (*a*) represents the standard star connection, diagram (*b*) represents the interconnected star with the neutral leads unchanged, and diagram (*c*) represents the interconnected star with the main leads unchanged. This is equivalent to reducing the armature conductors so that the voltage generated for a given flux will be 86.7 per cent of that for the straight star connection. Therefore, to get the same voltage, the field strength must be increased while the damagnetizing effect of the armature is decreased. The reactance is practically unchanged. So long as the power factor remains leading this expedient increases the stability of the machine without any extra duty on the field because of the inherently small field excitation required under such conditions. However, when the load on line increases to the extent that the power-factor becomes sufficiently low and lagging to overload the field with the machine operating at the high induction the armature must be reconnected for straight star and the machine operated under the normal lagging condition for which it was designed. With the lagging power factor there is, of course, no occasion or necessity for increased stability.

Such an expedient as the above scheme might, in some cases, be used on generators when charging the

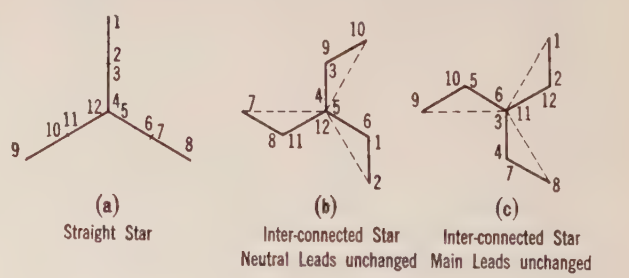



Fig. 8—Interconnected Star

line on starting up the system, even though the normal operation be at lagging power factor. For instance, assume there are several generators on a system and it is necessary that each machine be able to charge the line. Instead of increasing the size of the machines to make them inherently of such proportions as to be able to charge the line it might be possible to use machines of normal or of less abnormal design by bringing out the leads on the machines to a panel in such a way as to permit the connection shown in diagram (*c*) Fig. 8 during the period prior to the building

up of the load. After the load built up to the limit of the field capacity of this one machine, one or more of the other machines could be put on the line to carry the load while the first machine was disconnected from the line and the armature connection changed to the normal star connection. This machine could then be put back on the line, if desired. The feasibility of this method of operation will depend on local conditions. If the occasions for charging the line were very seldom and if the leads were brought out of the machine to a panel with a switching arrangement that would permit a quick change in connections, it is possible that it would be more economical and satisfactory in some cases to use this or some other special connection than to increase the size and cost of the generator to meet the special and infrequent line charging condition. Connecting the winding in interconnected star increases the line charging capacity of a normal machine about 30 per cent.

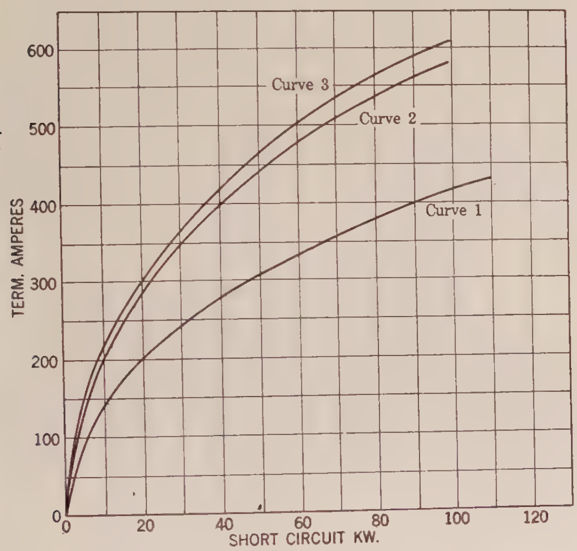



Fig. 9—Short-Circuit Loss Curves on 1080-Kv-a., 2400-Volt, 3-Phase, 60-Cycle, a-c. Motor

Care must be taken in the use of special connections of the winding such as interconnected star to insure the proper distribution and relation of the armature reaction set-up by the current in the armature winding. With the ordinary connection shown in diagram (*b*) or (*c*), Fig. 8, the armature reaction is not evenly distributed around the machine. This is equivalent to a resultant single-phase action and gives a negative sequence component to the rotation of the armature m. m. f. This results in excessive losses in the pole faces and damper winding, if any is used. However, by means of a special connection for interconnected star the desired result can be obtained with very little increase in losses. In this special connection the phase groups are split and the interconnection between phases made every pole. It results in a much more even and uniform distribution of the armature m. m. f. than does the usual interconnected star and hence does not produce the bad effects found in the latter connection. This difference in the distribution of the armature m. m. f. for the straight star, the usual interconnected star, and the special interconnected star can be readily seen by plotting the armature reaction or m. m. f. for the several conditions. The m. m. f. for the usual interconnected star is irregular in shape for a given pole and varies in shape and magnitude from pole to pole, while the shape of the m. m. f. for the special interconnected star is very similar to that of the straight star. This analysis is also borne out by actual test results of short-circuit loss on a 1080-kv-a., 900-rev. per min., 2400-volt, 60-cycle machine with the usual and special interconnected star windings as shown in Fig. 9 by curves 1 and 2, respectively. Curve 3 shows the short-circuit loss for a straight star connection. It is readily seen from these curves that there is quite an extra loss for the usual interconnected star and that there is very little additional loss over the straight star for the special interconnected star. The only objection to the special interconnected star is that the number of changes in connections is greater than for the usual interconnected star by the ratio of the number of poles in a given machine. Therefore, machines which are to operate for long periods with interconnected star and then changed permanently to the straight star should have the special connection, while those which operate only for short periods with interconnected star and require that the changes in connection be made quickly, and often, should have the simpler connection. This extra loss for short periods would not be serious and the standard connection would permit the 9 leads to be brought out of the machine to a panel for rapid connection as referred to above.

## Overspeed and Flywheel Effect

A reasonable overspeed is, of course, necessary for any waterwheel generator. However, it is often possible to influence it considerably by the design of the waterwheel and it should be kept as low as the economical design of the waterwheel will permit. Unusually, high overspeed, especially in the case of large high speed machines, often necessitates difficult and expensive mechanical construction and may even require a reduction in the normal running speed.

There seems to be a tendency to base the hydraulic design on a standard speed regulation and corresponding flywheel effect, regardless of the magnitude of the probable load changes. In the large units and stations usually involved in long transmission systems sudden load changes seldom amount to any considerable percentage of the connected generator rating. Under such conditions a larger percentage regulation (with 100 per cent load change) can be permitted than in the case of smaller systems in which sudden load changes may be a large percentage of the connected

generator rating. It appears to the writer that sufficient consideration is not given to actual operating conditions and that over conservative values of flywheel effect are sometimes specified on units which actually operate with very small changes in load. Flywheel effect, of course, does not become a factor in the generator design unless it exceeds the value determined by normal design. Abnormal flywheel effect always means increased cost. Either a separate flywheel must be furnished, the weight of the spider increased or the diameter of the machine increased. Even if the increased flywheel effect can be obtained at an increased diameter without increased weight, the larger diameter machine is generally more expensive. Also if the rotor weight is increased on a given diameter the mechanical parts, especially in the case of a vertical unit, must be made heavier and more expensive. In the case of large high speed units and where it is not possible to get the required flywheel effect by increasing the spider weight of a normal machine nor permissible to use a separate flywheel and it becomes necessary to increase the diameter, the stresses may increase to the extent that special and expensive construction or material may become necessary.

### Synchronous Condensers

The great increase in the size and length of transmission systems in recent years has greatly increased the demand for, and importance of, synchronous condensers for correcting power factor and regulating and stabilizing the voltage of the lines.

### Leading and Lagging Operation

The majority of condensers are designed primarily for leading power factor or over-excited operation. However, on long lines where the leading current drawn by the line may be sufficient to increase the receiver voltage at light loads the condenser may be called upon to operate at a lagging power factor or under-excited, in order to maintain the normal receiver voltage. The effect of lagging current on a condenser normally designed for leading power factor operation is similar to that of leading current on a generator normally designed for lagging power factor operation and previously referred to. Anything that is done to a normal machine without increasing its weight or cost, to improve its stability under lagging power factor operation increases the duty on the field at the leading power factor condition. A condenser may be made with normal proportions and at normal costs to operate at full kv-a. leading or at full kv-a. lagging, but not at both. A machine designed to operate at both leading and lagging power factor (above a normal amount) must have increased proportions and cost. A normal condenser designed for leading power factor operation can carry about 50 per cent, of its rated capacity lagging. Although it is possible to operate condensers of salient pole construction at considerable reversed excitation (about 50 per cent of no-load excitation) and get still more lagging capacity it is not considered good practise to operate below zero excitation on account of possible instability. With excitations below zero the machine is likely to become unstable and drop out of step during minor line disturbances.

### Special Connections and Stability

The special armature connections referred to in the discussion of generators might also be used to increase the stability of condensers at lagging power factor operation in the case of a line operating at a small initial load requiring lagging condenser capacity and that will have a large ultimate load requiring leading condenser capacity. This would require that the special connection be used initially and that the machine be reconnected, straight star, for the ultimate and normal condition. Although lagging capacity increases the cost of a condenser which normally operates at leading power factor it increases the stability of the machine and is quite desirable at extreme overloads on the system when the regulation limit or pull-out point of the line is approached.

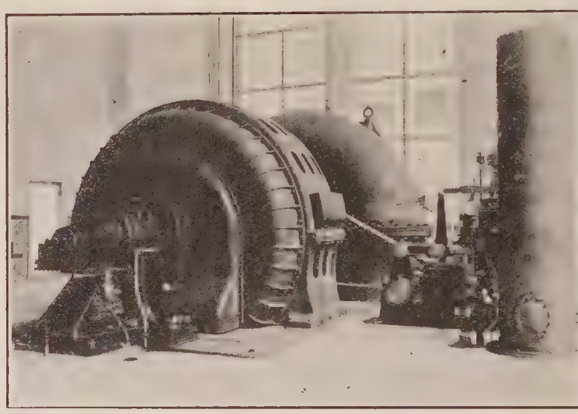


Fig. 10—14,285 Kv-a., 6600-Volt, 3-Phase, 60-Cycle, 450-Rev. per Min. Waterwheel Generator

### Construction

Synchronous condensers are usually built at the highest economical speed and resemble horizontal water wheel generators in general appearances and construction. They are usually designed for very little (about 25 per cent) overspeed as under usual conditions no overspeed need be anticipated. However, occasionally manufacturers are called upon to proportion the machines to meet the overspeed of the generators to which the condensers will be connected. In such cases the condensers are usually on isolated lines or in the power station with the generator. A 15,000-kv-a., 6600-volt, 3-phase, 450-rev. per min. synchronous condenser being built for the

City of Seattle is required to meet such a condition. The condenser will be the same as the generator shown in Fig. 10 except for the frame and bearings. A new type of damper winding is employed on account of the unusual overspeed of this condenser which is described later.

### Damper Windings

In large condensers, the damper winding constitutes one of the most difficult design problems and has given considerable trouble in condensers in operation. The early design employed a complete ring without joints (on account of stress conditions) with bars bolted to the rings. This design is satisfactory in smaller units and when the current density at the joint between bar and ring can be moderate. In larger units some trouble has been experienced due to burning between the bars and end rings and this has led to the development of design with welded joints. Welding the bars to a continuous end ring is not a wholly satisfactory solution on account of the impossibility of removing a pole or field coil without destroying the damper winding. Bars cannot be welded to a sectional end ring (except for moderate stress conditions) on account of the effect of the welding heat on the strength of the end ring segments. A construction has been worked out that has the advantage of the welded joint and the strength of the continuous end ring without the disadvantages mentioned above. The construction is shown in Figs. 11, 12 and 12A. The bars are welded to a copper segment of angle section and these segments are bolted to the continuous copper ring. This ring is rolled copper strap with a brazed scarf joint located opposite one of the poles. The ring is on the edge and hence has maximum mechanical strength as well as ample contact surface at the various sections to which it is bolted.

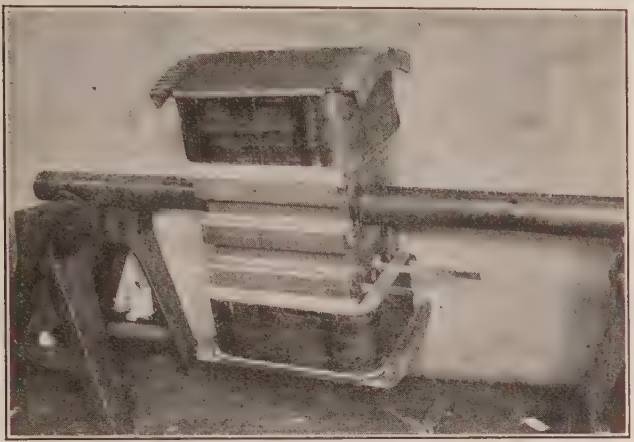


Fig. 11—Partially Assembled, 4-Pole Rotor, showing Welded Damper Construction

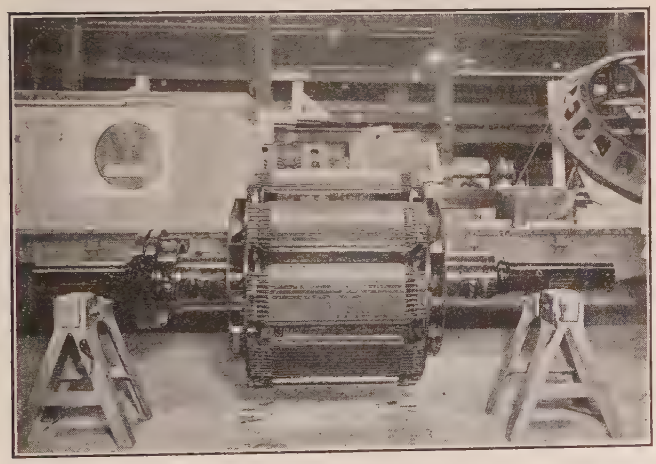


Fig. 12—Rotor of 5000 Kv-a., 11,000-Volt, 60-Cycle, 720-Rev. per Min. Synchronous Condenser with Welded Damper Winding

This construction has proved quite satisfactory and is generally applicable to high-speed condensers. Machines with this damper construction have been run at very considerable overspeed in factory tests. It is believed that this design constitutes a distinct advance in damper winding construction and removes one of the limits that previously existed in the design of large high-speed condensers.

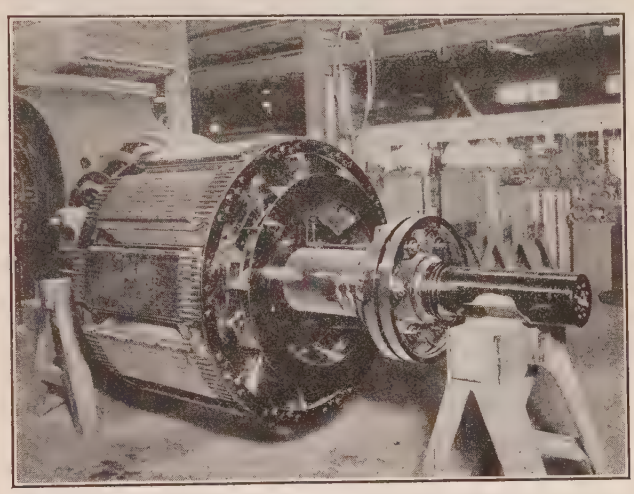


Fig. 12A—Another View of Rotor in Fig. 12

### End Bells

As the necessity for locating condenser substations in residential and business districts increases, the question of noise becomes of increasing seriousness. With the high speed to which it is necessary to go to obtain the most economical design, the moderate and large condensers are inherently noisy even though the fans and other projecting parts may be specially proportioned to minimize the noise. Therefore, where noise is objectionable, it is advisable to totally enclose the condenser so as to contain and suppress the noise within the machine. To further suppress or muffle the noise, the enclosing parts, such as the frame and end bells, should be designed so that ducts leading to

the outside of the building may be attached for bringing in the cooling air and discharging the hot air. Even in uninhabited or mill districts where noise will not be objected to by the surrounding community it is often advisable and profitable to enclose the condensers to provide additional comfort for the station operators and attendants. Enclosing has sometimes been objected to in the past on account of additional weight

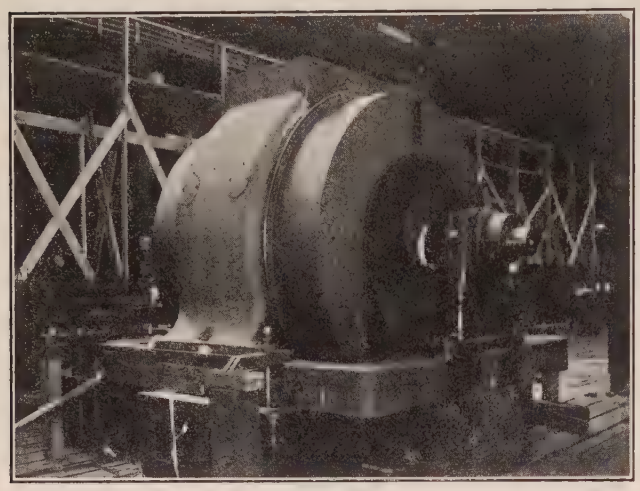


Fig. 13—5000-Kv-a., 11,000-Volt, 3-Phase, 60-Cycle, 720-Rev. per Min., Synchronous Condenser with Sheet Steel End Bells

and difficulty of handling the heavy cast iron end bells. However, this objection is largely eliminated by the use of sheet steel end bells. With the improvements in their design in recent years sheet steel end bells do not detract from the appearance of machines on which they are used and on account of their decreased cost and weight and the ease of handling their use is

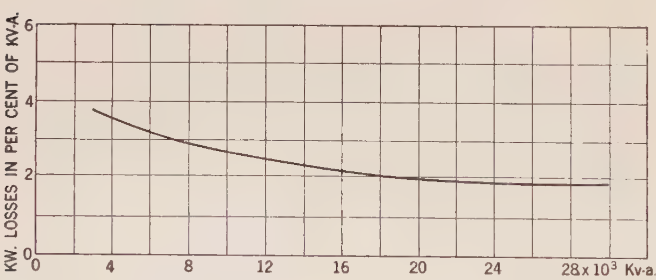



Fig. 14—Synchronous Condenser Losses

strongly recommended. Fig. 13 shows a totally enclosed 5000-kv-a., 11,000-volt, 720-rev. per min. condenser with totally enclosed frame and double sheet steel end bells. The frame has a rectangular opening at both top and bottom and the depth of the frame is such that either opening may be closed and all the hot air carried around the frame and discharged at the other opening through ducts, if any are provided. The outer sheet steel end bells are arranged so that ducts may be readily attached. Even on machines which are semi-enclosed and do not have the outer end bells, the use of sheet steel for the inner bells is recommended for reasons given above.

## Losses

In the case of generators there is usually very little doubt as to their necessity. If a certain load is to be furnished the required generator capacity is rather definite. However, in the case of condensers the required capacity is not so definite and their economical necessity is often debatable. Condensers have, therefore, had to justify their use by results and in the process great importance has been placed on low losses. It has, therefore, been necessary to reduce them to a minimum. This has been made possible by the use of improved core plate material, improved fan design and refinements in general design. The curve in Fig. 14 shows the low losses it is possible to obtain on

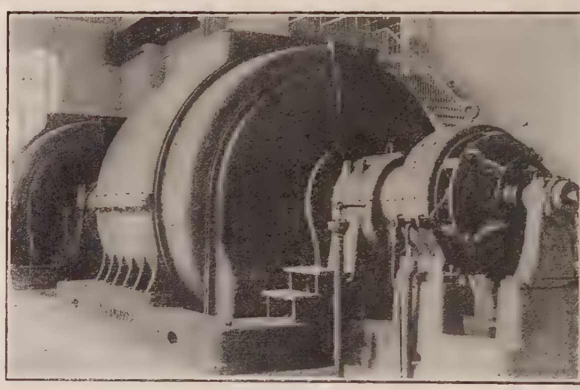


Fig.15—Two 20,000 Kv-a., 11,000-Volt, 3-Phase, 60-Cycle, 600-Rev. per Min. Synchronous Condensers

synchronous condensers designed for 11,000 volts or less and with all modern improvements and refinements in design. Guarantees will usually be about 10 or 15 per cent above this curve. As an example, the segregated full-load losses for the two 20,000-kv-a. 11,000-volt, 3-phase, 60-cycle, 600-rev. per min. condensers built for the Pacific Gas and Electric Company are given below.

SEGREGATED FULL-LOAD LOSSES ON TWO 20,000 KV-A. 11,000-VOLT, 60-CYCLE, 3-PHASE, 600-REV. PER MIN. SYNCHRONOUS CONDENSER

| Segregation | Kw. Losses No. 1 | Kw. Losses No. 2 |
|---|---|---|
| Armature $I^2\,R$ Loss at 75 deg. cent. | 57.3 | 58 |
| Load or Stray Power Loss (100 per cent of tested sh. cir. loss) | 46.2 | 45 |
| Field $I^2\,R$ Loss at 75 deg. cent. | 63.3 | 60 |
| Core Loss | 118.0 | 113 |
| Friction and Windage Loss | 115.0 | 115 |
| Total Losses | 399.8 | 391 |

A photograph of the two machines is shown in Fig. 15. They are installed on the Mount Shasta system and are designed for a lagging capacity of 12,000 kv-a. Fig. 16 is a photograph of the stator of one of the units showing the armature winding and coil bracing. The connections between armature coils and groups were transposed in such a manner as to reduce the eddy

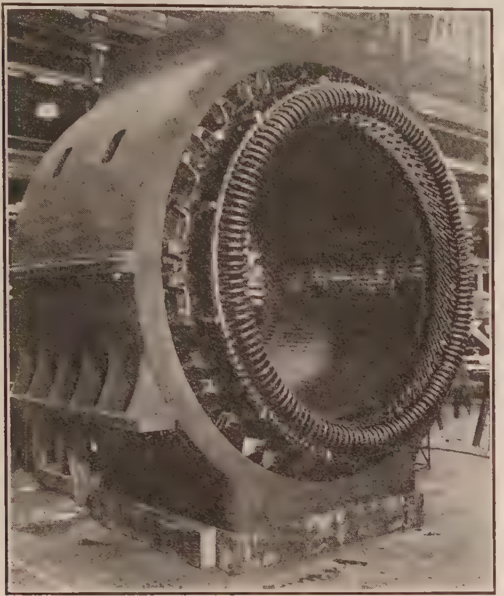


Fig. 16—Stator of 20,000 Kv-a. Synchronous Condenser

current loss to a low value. This is partially responsible for the fact that the kw. losses on this unit were reduced to 2 per cent of its kv-a. rating. A photograph of the rotor of one of the units showing the coil bracing, fans, etc. is shown in Fig. 17. The shaft has a forged half coupling to permit its possible use as part of a frequency changer set in the future.

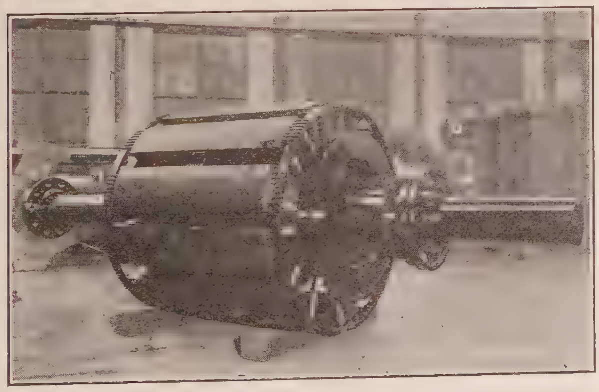


Fig. 17—Rotor of 20,000-Kv-a. Synchronous Condenser

Starting Kv-a.

By the use of oil pressure in the bearings during starting and with improvements in damper design it is possible to start synchronous condensers of 5000 kv-a. capacity and over on 15 per cent of normal kv-a. To obtain such low starting kv-a., however, requires a very low starting voltage, and unless low starting kv-a. is extremely important, it is advisable to increase the starting kv-a. to 25 or 30 per cent and obtain more margin in starting voltage, reduce the difference in the starting and running voltage, and reduce the time required to reach synchronism.

Tests on one of the 20,000-kv-a. condensers referred to above showed that it would start on approximately 2800 kv-a., at 19 per cent voltage and come up to speed in three minutes. However, at the minimum auto-transformer starting voltage tap, of approximately 27 per cent voltage, the machine takes approximately 6000 kv-a. and comes up to speed in a little over one minute.

The latest equipment for furnishing the oil pressure during starting consists of a small two cylinder pump driven by a one horse power motor. The pressure usually required for starting varies from 400 to 800 lb. per sq. in. However, the equipment is capable of

Fig. 18—Two-Cylinder Oil Pressure Pump and Motor

furnishing a sufficient quantity of oil at 1000 to 1200 lb. per sq. in. when necessary. A photograph of the pump is shown in Fig. 18.

## LIGHTING NEW YORK SUBWAY AND ELEVATED CARS

The following item gleaned from a recent issue of the *Electric Railway Journal* presents the monetary side of safety and convenience for the patron as regards the lighting in a city railway system:

"It will cost $500,000 this year to light the subway and elevated trains, station platforms, track signals, and other facilities of the Interborough Rapid Transit Company, New York City. Of all the energy generated in its power plants 6.6 per cent will be required for electric light.

There are 320,000 outlets throughout the system, including those for 50,000 incandescent lamps in the subway cars, and 88,000 on the subway platforms and in the tunnels. Ninety per cent of the last-named burn continuously. The elevated trains require 45,000 lamps for lighting.

"Track signals account for additional thousands of lamps. Every 400 ft. along the subway track there is a blue lamp indicating the location of an emergency switch for shutting off power in the third rail."

# Operating Performance of a Petersen Earth Coil

BY J. M. OLIVER and W. W. EBERHARDT

Associates, A. I. E. E.

Both of the Alabama Power Co., Birmingham, Ala.

***Review of the Subject.***—*This paper is a report on the Alabama Power Company's operating experience with a Petersen Earth Coil installed between the neutral and ground of a 120-mile, 44,000-volt, 3-phase, star-connected, 60-cycle system.*

*A Petersen coil is essentially an inductive reactance of such value as to maintain resonance with the capacitance of the system to ground at the fundamental system frequency. With a ground on one wire the current through the fault is reduced to such a low value as to prevent maintenance of an arc. Therefore, on the assumption that the majority of phase-to-ground short circuits start as insulator flashovers, the installation of such a device as a Petersen coil which would snuff out flashover arcs should considerably reduce the number of interruptions to the line.*

*By means of proper relaying, cases of trouble outside of the operating sphere of the Petersen coil, such as phase-to-phase short circuits and solid grounds have also been successfully taken care of.*

*Previous to the installation of this coil numerous interruptions to service were experienced on this system during lightning storms, which are unusually severe in the territory covered by these lines. This system, therefore, offers an ideal location for a trial installation of the coil.*

*Since the installation of the coil the number and duration of interruptions due to lightning flashovers have been reduced by 83.5 per cent and 94 per cent respectively. Several doubtful actions, however, have occurred during switching operations, indicating the presence of unusual phenomena. By proper relaying it is hoped to prevent the recurrence of such action. Further tests are also contemplated to investigate the unusual phenomena accompanying certain operating conditions.*

CONTENTS



---

A PETERSEN Earth Coil, or neutral grounding reactor was installed on the Alabama Power Company's Lock 12-Vida 44,000-volt system on October 12, 1921, and, with the exception of short intervals during testing and construction periods, has been in continuous service to date. Although Petersen coils have been in use in Europe for sometime, the Lock 12 installation is perhaps the first one in this country which has been in actual continuous operating service for a considerable length of time, and it has consequently aroused a great deal of interest.

The purpose of this paper is to give a description of the Lock 12 installation and a complete account of its operating performance to date. The theory of operation of the Petersen coil together with a report of tests made at Lock 12 on December 3-4, 1921, and January 18-19, 1922, in conjunction with the General Electric Company, are presented in a companion paper by Mr. W. W. Lewis.

## Description of Lines

The Lock 12-Vida 44,000-volt system is a three-phase, star-connected, 60-cycle system, consisting of a main line from Lock 12 to Vida having tap lines to Mitchell Dam and Clanton, an east branch from Vida to Montgomery, and a west branch from Vida to Marion as shown in the single-line diagram Fig. 1.

These lines are not a part of the main 44,000-volt network, but form a separate and very important system, as they are the main source of supply to the cities of Montgomery, Selma, Marion and Clanton, having a combined population of over 60,000. The maintenance of service to these lines consequently is of prime importance, and the application of any device such as a Petersen coil, which would reduce the number of interruptions could be well demonstrated here. Furthermore, the territory covered by this system is subjected to lightning storms of unusual frequency and intensity resulting in numerous line outages due to insulator flashovers, the very trouble from which the Petersen coil promises relief. These lines were, therefore, selected as the most ideal location for a trial installa-

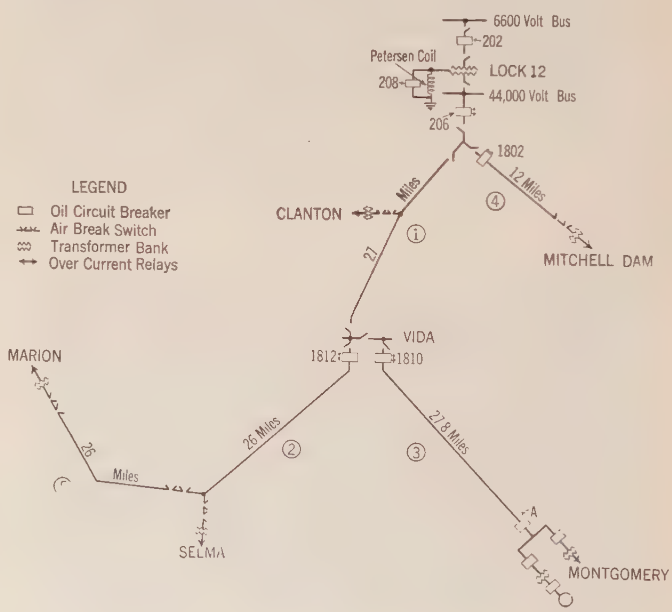



Fig. 1—Lock 12—Vida 44,000-Volt System

1. So named after its inventor Prof. W. Petersen, of Darmstadt, Germany.

*Presented at the Spring Convention of the A. I. E. E., Pittsburgh, Pa., April 24-26, 1923.*

tion of the Petersen coil on the Alabama Power Company's system.

The physical characteristics of the lines comprising the Lock 12-Vida system are as follows:

| Line | Length miles | Number of circuits | Conductor | Spacing | Insulation |
|---|---|---|---|---|---|
| Lock 12-Vida | 27.0 | 1 | (168,000 cm. Al. steel core) | 5-3.5-6.1 | 50-kv. pin type |
| Mitchell dam tap | 12.0 | 1 | No. 4 Alum. | 3.5-3.5-5 | 50-kv. pin type |
| Clanton tap | 1.3 | 1 | No. 4 Cu. | 5-3.5-6.1 | 50-kv. pin type |
| Vida-Montgomery | 27.8 | 1 | (168,000 cm. Al. steel core) | 7-4.5-8.3 | 4 O. B. suspension units |
| Vida-Marion | 52.0 | 1 | No. 4 Cu. | 5-3.5-6.1 | 50-kv. pin type |

These lines are all of pole construction with wooden cross arms giving conductor spacings as shown in Figs. 2, 3 and 4 of the various lines. There are no transpositions in any of the lines.

All the lines, with the exception of the Lock 12-Mitchell Dam line, are equipped with one 3/8-in. 7-strand steel, overhead ground wire grounded at each

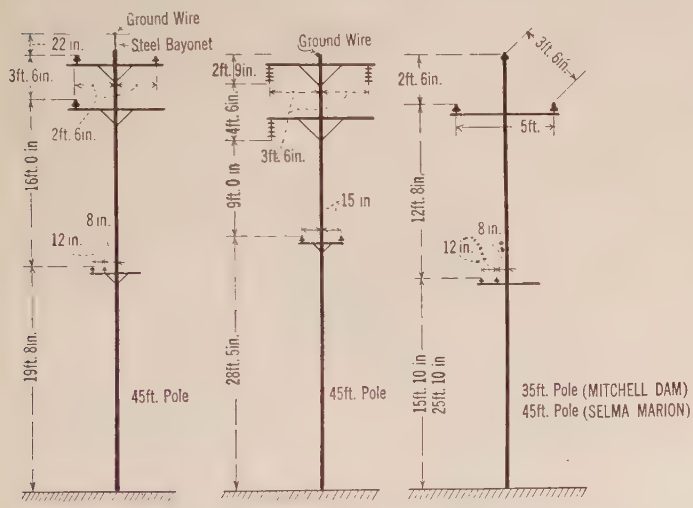



Fig. 2—Lock 12—Vida-Selma Line, Facing Selma
Fig. 3—Vida-Montgomery Line, Facing Montgomery
Fig. 4—Lock 12—Mitchell Dam Line, Selma-Marion Line

pole. The insulator pins are not grounded, but the cross braces at each pole are connected to the grounding wire. On the Lock 12-Mitchell Dam line, which has no overhead ground wire, a lateral grounding wire runs up each pole to the top insulator pin.

This system is fed from Lock 12 through a 9000-kv-a. transformer bank consisting of three 3000-kv-a. single-phase, step-up transformers, connected 6600 volts delta on the low-tension side to 44,000 volts star on the high-tension side. The Petersen coil is connected between the neutral of the 44,000-volt winding and ground, as shown in Fig. 5.

## Description of Petersen Coil

The Petersen coil is an oil-immersed, water-cooled, reactor without core having a continuous rating of 795 kv-a. at 26,540 volts, 60-cycle, with a 55 deg. cent rise. The reactor is designed to have a reactance of 2015 ohms with 5 per cent taps ranging down to 811 ohms. Ex-

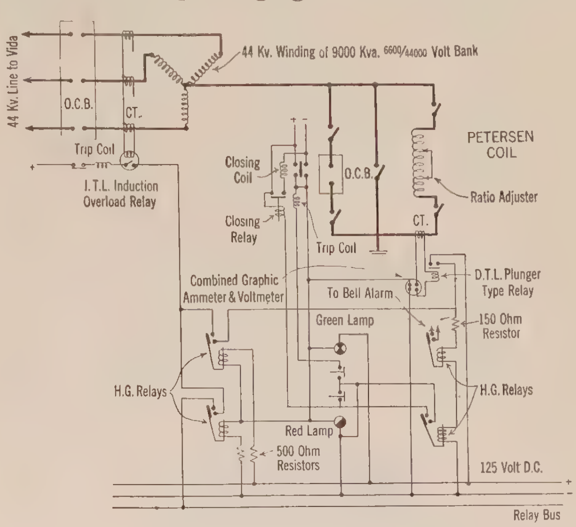



Fig. 5—Lock 12—Petersen Coil Installation—Schematic Diagram of Connections

ternal and internal views of the reactor are shown in Figs. 6 and 7 respectively.

The numerous taps on the reactor are equipped to take care of various combinations of the present lines in service and proposed future extensions. The Petersen coil operates on the principle of an inductive reactance resonated at the fundamental system frequency with the capacity reactance of the system to ground—hence, for every setup on the system involving different combinations of lines in service, a correspond-

Fig. 6—Oil-Insulated, Disk-Coil, Water-Cooled Reactor

ing value of inductive reactance will be required equivalent to the capacity reactance of lines in service.

The setting of the reactor to maintain resonance is conveniently accomplished by means of two ratio adjusters, with control handles extending through the tank cover, enabling adjustments to be made in but a few minutes time.

Following is a table showing the adjustments corresponding to various combinations of lines in service:

| Lines in Service (See Fig. 1) | Reactance ohms | Adjuster "A" | Adjuster "B" |
|---|---|---|---|
| 1-2-3-4-5 | 1015 | IV | V |
| 1-2-3-5 | 1128 | IV | III |
| 1-2-3-4 | 1207 | IV | II |
| 1-2-4-5 | 1335 | I | V |
| 1-2-3 | 1410 | I | III |
| 1-2-5 | 1538 | I | I |
| 1-3-4 | 1630 | III | I |
| 1-2-4 | 1735 | II | V |
| 1-3 | 1915 | II | II |
| 1-2 | 2015 | II | I |
| 4 | Reactor out of service. | Neutral solidly grounded. | |

## Control and Relay Connections

Since the Petersen coil functions only in cases of insulator flashover, which experience shows are the cause of the majority of line troubles, protection must nevertheless, also be provided for the occasional cases of solid grounds, and phase-to-phase short circuits.

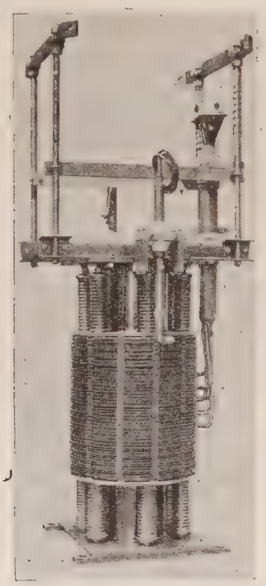


Fig. 7—Disk-Coil, Oil-Immersed, Water-Cooled Reactor

Phase-to-phase short circuits can be cleared by regular overload relays installed on the line switch. A solid ground on a Petersen coil system, however, will have no effect on the line relays and other means must be provided to clear the trouble, unless it is desired to continue operation with a phase grounded. In the Lock 12 installation an oil circuit breaker is connected across the reactor, as shown in Fig. 5. This breaker is normally open, but closes automatically in cases of solid grounds on the lines, thereby grounding the neutral solidly, after which the overload relays on the line switch will operate as in a normal grounded system and clear the trouble.

The control scheme is shown in detail in the schematic diagram Fig. 5. A definite time limit overcurrent relay is connected in the secondary of a current transformer, the primary of which is in series with the Petersen coil and ground. This relay is given a time setting of approximately two seconds. Normally, flashovers are cleared by the Petersen coil in 5 to 15 cycles, consequently, when the reactor current holds on for several seconds it is evident that the reactor is not functioning, and it can be taken as a safe indication that a solid ground has developed on the line. At the end of two seconds the relay contacts will close, thereby energizing two auxiliary relays, one of which causes the grounding switch to close and the other ringing a bell alarm to warn the operator that the line is in trouble. The grounding switch on closing then, short circuits the reactor and the regular overcurrent relay scheme comes into action to clear the trouble. This short-circuiting switch must be opened by hand to again place the reactor in service. Five disconnect switches are provided, as shown in Fig. 5, whereby the reactor or grounding switch can be isolated for clearance or for testing.

For a permanent daily record of the operations, a curve drawing ammeter and voltmeter combined in one instrument is provided; the ammeter indicating the current passing through the reactor, and the voltmeter indicating when the grounding switch is open or closed. A typical chart showing both ammeter and voltmeter actions is shown in Fig. 8. The scale on the chart applies only to the inner or current curve, and on the particular day shows an indication of 21 amperes at

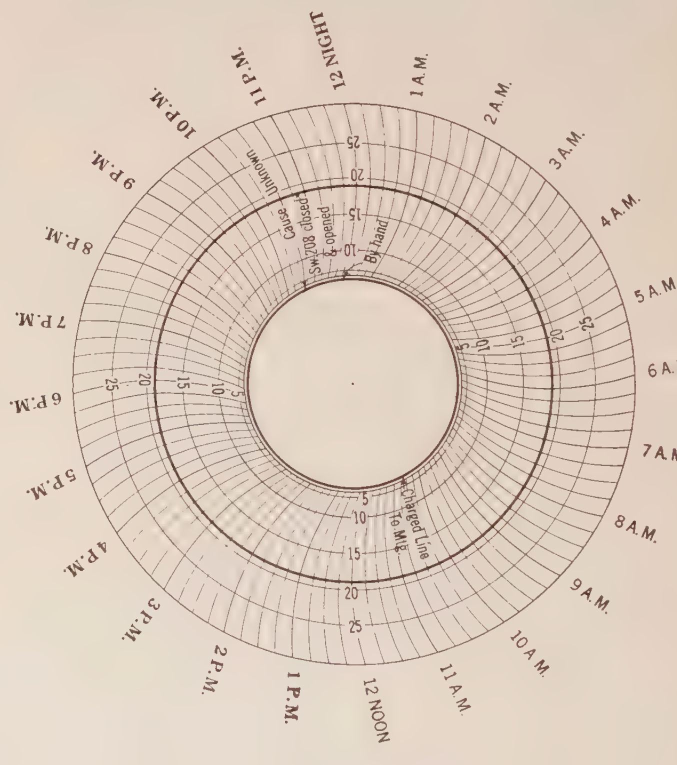



Fig. 8—Record of Alternating-Current Ammeter

10:40 p. m. No scale applies to the outer or voltage curve; it shows only a notched indication when the grounding switch operates. On this chart, such a record is shown slightly ahead of the 21-ampere current indication. In reality, these indications occurred only two seconds apart; the 15 minute separation on the chart being necessary to prevent interference between the two pens.

After the reactor had been in operation for some time,

several flashovers occurred (July 7, August 25, 1922 and Feb. 23, 1923) on the 44,000-volt bus insulators at Lock 12, when the line switch was opened automatically or by hand. At these times the Petersen coil was in service. Whether it was in any way responsible for the flashovers, is not known, but, as a precaution against similar troubles in the future, the line relays have been electrically interlocked with the control circuit of the grounding switch as shown in Fig. 5, insuring that the grounding switch is first closed before the line switch can open on relay action. This interlocking, however, has the disadvantage of slowing up the relay operation on phase-to-phase short circuits. The operators likewise have instructions to always close the grounding switch before doing any line switching.

## Operation

Table I is a log of all the Petersen coil operations, from October 12, 1921, to March 1, 1923, as read from the charts of the combined graphic ammeter and voltmeter. From October 12th to November 30, 1921, the graphic ammeter was equipped with a 30-ampere coil instead of a 5-ampere coil, which would give only 1/16 inch deflection on the chart for 22 amperes. Since flashovers last only 5 to 15 cycles, it is thought that during this period the Petersen coil may have functioned on a flashover to which the ammeter did not respond. One severe lightning storm occurred in the period during which no operations were recorded. All indications from December 1, 1921 to date have been with a 5-ampere ammeter coil in service.

## Flashovers

A study of the log showed that the majority of operations gave indications of only 5 to 10 amperes, whereas, for a clear cut flashover to ground with all lines in service, the neutral current should be 22 amperes. These low indications may have been due to

1. A time lag in the swing of the ammeter pen, the arc having been snuffed out before the pen accomplished its full swing.
2. A resistance ground instead of a clear ground on flashover due to the fact that the insulator pins are not grounded.

The latter is a plausible explanation of the low-current indications and it is believed that, for positive action of the Petersen coil, the insulator pins should be grounded.

A summary of the operations is shown in Table II where it is noted that there have been 168 flashover indications, which seems rather high for the period covered. It may be that all of the low-current indications are not the result of flashovers, but if such is the case it would be difficult to draw a dividing line between the true flashover indications and those due to other causes. The ammeter scale is considerably contracted from 0 to 5 amperes whereas above 5 amperes the unit scale divisions are more uniform, making an ampere division above 5 amperes on the chart nearly equal to the division representing 0-5 amperes. Since the 5 ampere indications are comparatively small, a tentative classification has been made in Table II of the flashover indications of 6 amperes and above, and those below 6 amperes.

## Faulty Operations

In all there were only two operations which could be strictly classed as faulty operations. These occurred on December 26th at 5:34 p. m., and on August 8 at 4:55 p. m. when the flashovers held on long enough to close the grounding switch and cause the overcurrent relays to open the line. The line in each case went back in service properly, indicating that the trouble was not a solid ground, but a flashover which the Petersen coil evidently failed to clear.

## Solid Grounds and Phase-to-Phase Circuits

The summary shows that there were a total of 29 cases of solid grounds and phase-to-phase short circuits due to line, transformer, and bus trouble, which are outside of the operating sphere of the Petersen coil. All of these cases, however, were successfully cleared by the line relays. Of these operations, however, three are considered doubtful—namely, on July 7th, August 25th and February 23rd when, after the line switch opened, a string of insulators on the 44-kv. bus between the transformer and the line switch flashed over. The flashover in each case was across 5 units of O. B. suspension insulators, indicating the presence of an unusually high voltage. The insulator units all meggered well on being tested after the trouble, indicating that the troubles were not due to insulator failures. It seems that some high-voltage transient was introduced in these cases due to the disconnection of the line capacitance. It is proposed to make further tests to verify this point. As stated before, all switching, both hand and automatic, is now being done with the grounding switch closed—that is, with the reactor out of service.

## True Flashovers in which Grounding Switch Closed

There were seven operations in which the grounding switch closed, but no line switch opened, and no disturbance occurred on the system. As the closing of the grounding switch seemingly indicated a solid ground on the system, the only explanation for these operations is that a flashover or solid ground held on long enough (two seconds) to cause the definite time limit overcurrent relay to operate, but cleared before the contacts of the grounding switch closed. These operations are all considered correct as there were no interruptions to service.

## Neutral Current Indications on Switch Operations

There were twenty cases of reactor current indications coincident with switching operations on the lines under conditions when the neutral current must have been zero. These indications may have been due to the

TABLE I

ALABAMA POWER COMPANY—LOCK 12 GENERATING STATION

Log of Petersen Coil Operation

| Date | Flashover to ground | Solid grounds | Phase-to phase short circuits | Automatic switch operations | Reactor current amperes | Operation | Nature of trouble and remarks |
|---|---|---|---|---|---|---|---|
| 1921 Nov. 16 | | | 11:28 a.m. | #206 opened | 0 | Correct | A surge occurred on the Montgomery line, and Line Switch #206 at Lock 12 opened automatically. Cause of trouble was the failure of a transformer at Prattville approximately 15 miles northwest of Montgomery. The fuses at transformer failed to clear trouble, and a single-phase line-to-line short circuit developed. The Petersen coil is not supposed to function under such conditions, so the line switch operation was correct. |
| Dec. 1 | 10:40 p.m. | | | 208 closed | 21 | Correct | Weather cloudy. Cause unknown. No surge or outage occurred. Evidently a flashover or solid ground occurred and held on for two seconds at which time closing relay of the grounding switch was energized, but the flashover cleared before the grounding switch closed its contacts. |
| Dec. 2 | | | | | 7 | | Occurred 12:40 p. m. when switch #1802 was closed. Evidently due to switch contacts not closing together. |
| Dec. 8 | 5:18 p.m. | | | | 13 | Correct | Weather cloudy. No outage or surge occurred. |
| Dec. 8 | 5:20 p.m. | | | 208 closed | 22 | Correct | Weather cloudy. No outage or surge. Evidently a flashover or momentary ground occurred and held on long enough (2 sec.) to cause grounding switch to close, but cleared before grounding switch completed its closing operation. |
| Dec. 8 | 5:22 p.m. | | | | 15 | Correct | Weather cloudy. No outage or surge occurred. |
| Dec. 8 | 6:00 p.m. | | | | 15 | Correct | " " " " " " " |
| Dec. 8 | 6:12 p.m. | | | | 15 | Correct | " " " " " " " |
| Dec. 11 | 9:18 a.m. | | | 208 closed | 18 | Correct | Cause unknown. No lightning or rain occurred during this period. The ammeter pen would swing up to values noted, the grounding switch would close, but not latch, and then operation would repeat. On the fourth operation at 9:30 a. m. the grounding switch latched, but the current in the reactor held on at 6 amperes. No surge, however, occurred due to a short circuit. It is believed that the grounding switch blades did not make good contact, which were consequently changed two days later, and carefully checked to see that good contact was made. No cause could be found for the operation, but at the time, switching was being done at Prattville on the Montgomery section of the line. No arcs of unusual length were noted, however, when the air break switch at Prattville was opened. Considered correct as no outage or surge occurred. |
| | 9:20 a.m. | | | 208 closed | 17 | Correct | |
| | 9:25 a.m. | | | 208 closed | 20 | Correct | |
| | 9:30 a.m. | | | 208 closed | 19 | Correct | |
| Dec. 17 | 8:55 a.m. | | | | 8 | Correct | Weather fair. No outage or surge. |
| Dec. 17 | 9:00 a.m. | | | | 12 | Correct | Weather fair. No outage or surge. |
| Dec. 26 | 5:34 p.m. | | | 208 closed 206 opened | 25 | Faulty | Weather cloudy. Surge occurred when grounding switch closed. The line Switch opened automatically, but was reclosed 2 minutes later and remained in o. k. indicating that disturbance was a flashover and not a solid ground. |
| 1922 Jan. 6 | | 1:10 a.m. | | 208 closed 202 opened | 21 | Correct | Disturbance occurred when 206 was opened by hand to take line out of service to change a bad 44-kv. bushing on the transformer bank at Lock 12. Bushing, however, failed when line switch was opened resulting in a phase-to-ground short circuit. The grounding switch then closed automatically, and trouble was cleared by automatic operation of switch on low tension side of the transformer bank. |
| Jan. 16 | 2:35 p.m. | | | | 11 | Correct | Weather fair. No outage or surge. |
| Mar. 3 | | | 1:05 p.m. | 1802 opened | 2 | Correct | Switch 1802 first opened auto. When 1802 was reclosed #202 opened auto. Then 202 was closed and 1802 again opened auto. Patrolman later reported a tree down across Mitchell Dam Line. |
| | | | 1:35 p.m. | 202 " | 10 | " | |
| | | | 1:40 p.m. | 1802 " | 7 | " | |
| Mar. 8 | | | | | 8 | | Recorded at 12:25 p. m. when 1810 and 1812 were opened and reclosed at Vida by hand on prearranged switching orders. |
| Mar. 14 | | | 5:35 p.m. | 1812 opened | 5 | " | Lightning. Voltage surged from 115 to 108 volts. Switch 1812 reclosed after one minute. Evidently phase-to-phase short circuit. Reactor current probably due to switch operation. |
| Mar. 26 | | | | | 7 | | Recorded at 7:55 a. m. when 1810 was closed at Vida after a prearranged interruption to Montgomery. |
| Mar. 31 | 5:00 a.m. | | | | 19 | " | Severe lightning. No outage or surge. |
| | 5:07 a.m. | | | | 23 | " | " " " " " " |
| Apr. 11 | 2:40 a.m. | | | | 17 | " | Lightning. No outage or surge. |
| | 4:50 a.m. | | | | 8 | " | " " " " " |
| | 5:05 a.m. | | | | 6 | " | " " " " " |
| Apr. 23 | 5:28 a.m. | | | | 6 | " | Weather fair. No outage or surge. |
| | 7:30 p.m. | | | | 5 | " | " " " " " " |
| Apr. 27 | 3:10 p.m. | | | | 5 | " | Weather cloudy. No outage or surge. |
| Apr. 28 | | | 8:17 a.m. | 202 opened | 10 | " | Lightning at Lock 12. Voltage surged from 118 to 101 volts. Switch 202 was reclosed o. k. two minutes later. |

TABLE I (Continued)

| Date | Flashover to ground | Solid grounds | Phase-to-phase short circuits | Automatic switch operations | Reactor current amperes | Operation | Nature of trouble and remarks |
|---|---|---|---|---|---|---|---|
| Apr. 28 | 9:10 a.m. | | | | 5 | Correct | Lightning at Lock 12. No outages or surges. Operator at Lock 12 reported telephone noises at the times of these Petersen Coil actions. No disturbances were recorded on any of the other lines of the system at the time. |
| | 9:25 a.m. | | | | 5 | “ | |
| | 9:30 a.m. | | | | 5 | “ | |
| | 9:40 a.m. | | | | 5 | “ | |
| | 9:55 a.m. | | | | 5 | “ | |
| | 10:20 a.m. | | | | 5 | “ | |
| | 10:35 a.m. | | | | 5 | “ | |
| | 10:50 a.m. | | | | 5 | “ | |
| | 11:30 a.m. | | | | 5 | “ | |
| | 11:50 a.m. | | | | 6 | “ | |
| | 12:00 Noon | | | | 5 | “ | |
| | 12:10 p.m. | | | | 5 | “ | |
| | 12:20 p.m. | | | | 5 | “ | |
| | 12:35 p.m. | | | | 5 | “ | |
| | 12:40 p.m. | | | | 5 | “ | |
| | 12:50 p.m. | | | | 5 | “ | |
| | 1:00 p.m. | | | | 5 | “ | |
| | 2:05 p.m. | | | | 6 | “ | |
| May 1 | 4:30 p.m. | | | | 5 | Correct | Weather fair. No outage or surge. |
| May 2 | 3:35 a.m. | | | | 5 | Correct | Raining. No outage or surge. |
| May 6 | 11:35 a.m. | | | | 5 | Correct | Weather cloudy. No outage or surge. |
| May 8 | 8:28 p.m. | | | | 5 | Correct | Lightning at Vida. No outage or surge. |
| May 9 | 10:35 a.m. | | | | 5 | Correct | Cloudy. No outage or surge. |
| | 7:30 p.m. | | | | 5 | Correct | Lightning around Lock 12. No outage or surge. |
| May 10 | 4:20 p.m. | | | | 5 | Correct | Weather cloudy. No outage or surge. |
| May 16 | 1:15 a.m. | | | | 5 | Correct | Weather fair. Line was patrolled in the forenoon and an insulator found off its pin on pole #38 between Vida and Lock 12. A man was stationed at this point to watch and in case of trouble he was to place the insulator back on its pin. No further trouble occurred at this point. Considered correct operation as a ground was evidently prevented. Line was operated with loose insulator until 12:05 a. m. May 17 when an interruption was prearranged to place insulator back on pin. |
| | 1:20 a.m. | | | | 3 | Correct | |
| | 1:30 a.m. | | | | 3 | Correct | |
| | 2:40 a.m. | | | | 3 | Correct | |
| | 2:55 a.m. | | | | 3 | Correct | |
| | 3:05 a.m. | | | | 3 | Correct | |
| May 16 | | | 5:02 p.m. | 1812 opened “A” opened | 7 | Correct | Lightning was general over territory covered by line. Voltage surged from 116 to 106 volts. Grounding switch 208 did not close, indicating a phase-to-phase short circuit. Switch 1812 reclosed at 5:03 p. m. and Switch “A” at 5:07 p. m. O. K. Switch “A” opened because Montgomery Steam Plant was on at time. |
| May 16 | 5:17 p.m. | | | “A” opened | 11 | Correct | General lightning. Voltage surged from 113 to 108 volts. No outage at Lock 12. Evidently a flashover. Cause of Switch “A” opening not known. |
| May 17 | | | | | 10 | | Recorded when switch 206 was opened to take line out of service. |
| | | | | | 5 | | Recorded when switch 206 was closed to put line back into service. |
| May 17 | 9:50 a.m. | | | | 3 | Correct | Rain and lightning. |
| | 10:05 a.m. | | | | 3 | Correct | No outage or surge. |
| | 10:55 a.m. | | | | 3 | Correct | “ “ “ “ |
| | 11:10 a.m. | | | | 3 | Correct | “ “ “ “ |
| | 12:02 p.m. | | | | 3 | Correct | “ “ “ “ |
| | 12:20 p.m. | | | | 3 | Correct | “ “ “ “ |
| May 18 | 10:15 p.m. | | | | 5 | Correct | Weather fair. No outage or surge. |
| May 19 | 9:55 a.m. | | | | 5 | Correct | Lightning at Montgomery. No outage or surge. |
| May 20 | 9:16 a.m. | | | | 5 | Correct | Weather cloudy. No outage or surge. |
| | 8:05 p.m. | | | | 5 | Correct | Lightning. No outage or surge at Lock 12. Montgomery reported surges at these times. |
| | 8:20 p.m. | | | | 5 | Correct | |
| | 10:30 p.m. | | | | 5 | Correct | Lightning. No outage or surge. |
| May 21 | | | | | 6 | | Recorded when Switch #1802 was opened to take the Mitchell Dam line out of service. Current held on at 6 amperes until switch was reclosed. |
| May 21 | 2:32 p.m. | | | | 9 | Correct | Rain and lightning. No outage or surge. |
| May 24 | 12:20 a.m. | | | | 5 | Correct | Weather cloudy. No outage or surge. |
| | 12:29 a.m. | | | | 5 | Correct | “ “ “ “ “ “ |
| | 12:44 p.m. | | | | 5 | Correct | Lightning in vicinity. No outage or surge. |
| | 2:03 p.m. | | | | 5 | Correct | “ “ “ “ “ “ “ |
| May 25 | 10:50 a.m. | | | | 5 | Correct | Rain and lightning. No outage or surge. |
| | 10:56 a.m. | | | | 5 | Correct | “ “ “ “ “ “ “ |
| | 11:05 a.m. | | | | 5 | Correct | “ “ “ “ “ “ “ |
| | 11:25 a.m. | | | | 6 | Correct | “ “ “ “ “ “ “ |
| | 3:55 p.m. | | | | 5 | Correct | “ “ “ “ “ “ “ |
| | 7:00 p.m. | | | | 5 | Correct | “ “ “ “ “ “ “ |
| May 27 | 6:30 a.m. | | | | 5 | Correct | Raining. No outage or surge at Lock 12. Operator at Vida reported leaky insulator. Insulator was changed 12:00 o'clock that night. |
| | 8:15 a.m. | | | | 5 | Correct | |
| | 9:40 a.m. | | | | 5 | Correct | |
| | 10:20 a.m. | | | | 5 | Correct | |
| | 3:05 p.m. | | | | 5 | Correct | |
| | 6:20 p.m. | | | | 5 | Correct | |
| | 7:40 p.m. | | | | 5 | Correct | |
| | 8:00 p.m. | | | | 5 | Correct | |

TABLE I (Continued)

| Date | Flashover to ground | Solid grounds | Phase-to phase short circuits | Automatic switch operations | Reactor current amperes | Operation | Nature of trouble and remarks |
|---|---|---|---|---|---|---|---|
| May 28 | 9:18 a.m. | | | | 5 | Correct | Lightning at Lock 12. No outage or surge. |
| | 9:50 a.m. | | | | 5 | Correct | “ “ “ “ “ “ “ “ |
| | 7:20 p.m. | | | | 5 | Correct | “ “ “ “ “ “ “ “ |
| May 29 | 5:52 p.m. | | | | 5 | Correct | Weather fair. No outage or surge. |
| May 30 | 10:25 a.m. | | | | 5 | Correct | Raining. No outage or surge. |
| | 11:20 a.m. | | | | 5 | Correct | “ “ “ “ “ |
| | 8:25 p.m. | | | | 4 | Correct | “ “ “ “ “ |
| May 31 | 11:55 a.m. | | | | 5 | Correct | “ “ “ “ “ |
| | 5:15 p.m. | | | | 5 | Correct | “ “ “ “ “ |
| | 7:48 p.m. | | | | 5 | Correct | “ “ “ “ “ |
| | 10:52 p.m. | | | | 5 | Correct | “ “ “ “ “ |
| June 1 | 11:00 a.m. | | | | 5 | Correct | Raining. No outage or surge. |
| | 11:28 a.m. | | | | 5 | Correct | “ “ “ “ “ |
| | 12:15 a.m. | | | | 5 | Correct | “ “ “ “ “ |
| | 1:20 p.m. | | | | 5 | Correct | “ “ “ “ “ |
| June 4 | 1:28 p.m. | | | | 4 | Correct | Lightning at Lock 12. No outage or surge. |
| June 6 | 1:20 p.m. | | | | 5 | Correct | Raining at Lock 12. No outage or surge. |
| | 1:40 p.m. | | | | 5 | Correct | “ “ “ “ “ “ “ “ |
| | 2:00 p.m. | | | | 5 | Correct | “ “ “ “ “ “ “ “ |
| June 7 | 4:30 p.m. | | | | 5 | Correct | Lightning. No outage or surge. |
| | | | 4:57 p.m. | 1812 opened | 10 | Correct | Lightning. Voltage surged from 115 to 112 volts. Grounding switch 208 did not close. Switch 1812 was reclosed o. k. one minute later. Probably a phase-to-phase short circuit, although no evidence of such was found upon patrolling line. |
| June 12 | 11:20 a.m. | | | | 5 | Correct | Weather fair. No outage or surge. |
| June 13 | 7:05 a.m. | | | | 5 | Correct | “ “ “ “ “ “ |
| June 16 | 6:00 a.m. | | | | 10 | Correct | Lightning. No outage or surge. |
| June 17 | | | 1:47 p.m. | 206 opened | 5 | Correct | Lightning. Voltage surged from 118 to 108 volts. Grounding switch 208 did not close. Probably phase-to-phase flashover. Switch 206 was reclosed o. k. 2 minutes later. |
| | | | 2:35 p.m. | 1812 opened | 11 | Correct | Lightning. Voltage surged from 113 to 105 volts. Grounding switch 208 did not close. Probably a phase-to-phase flashover. Switch was reclosed o. k. one minute later. |
| June 19 | 12:00 Noon | | | | 7 | Correct | Sparrow caught between horns on lightning arrester causing flash to ground. No outage or surge. |
| June 20 | 5:40 p.m. | | | | 7 | Correct | Lightning at Lock 12. No outage or surge. |
| | 6:10 p.m. | | | | 5 | Correct | “ “ “ “ “ “ “ “ |
| | 6:25 p.m. | | | | 5 | Correct | “ “ “ “ “ “ “ “ |
| June 21 | 4:15 p.m. | | | | 5 | Correct | Weather cloudy. No outage or surge. |
| June 26 | | | 11:02 p.m. | 206 opened | 6 | Correct | Lightning. Voltage surged from 0-120 volts. Grounding switch 208 did not close. Switch 206 was reclosed o. k. 2 minutes later. Trouble evidently a phase-to-phase flashover. Reactor current probably recorded when 206 opened due to switch contacts not opening together. |
| June 28 | 4:15 a.m. | | | | 5 | Correct | Weather fair. No outage or surge. |
| | 11:12 a.m. | | | | 5 | Correct | “ “ “ “ “ “ |
| June 29 | 3:20 p.m. | | | | 4 | Correct | Lightning at Lock 12. No outage or surge. |
| July 3 | | | | | 9 | Correct | Recorded at 12:05 a. m. when 206 was opened on prearranged basis. |
| | | | | | 18 | Correct | Recorded at 12:07 a. m. when 206 was reclosed. |
| | 10:15 a.m. | | | | 5 | Correct | Raining. No outage or surge. |
| | 10:25 a.m. | | | | 5 | Correct | “ “ “ “ “ |
| | 2:10 p.m. | | | | 3 | Correct | Lightning. “ “ “ “ |
| | | | 3:10 p.m. | 1812 opened<br>202 “ | 6 | Correct | Lightning. Voltage surged from 116 to 96 volts.1 812 opened first but trouble developed in switch which caused 202 to open to clear trouble. Line switch 206 found in half open position showing it attempted to clear trouble, which it should have done as its relays are faster than those on 202. Trouble either a phase-to-phase short circuit on line, or started as a phase-to-ground short circuit on line and then developed into a phase-to-phase short circuit at switch 1812. Line was out only 2 minutes. |
| | 10:00 p.m. | | | | 3 | Correct | Lightning. No outage or surge. |
| July 4 | 3:32 p.m. | | | | 8 | Correct | Fair weather. No outage or surge. |
| July 7 | | 6:12 p.m. | | 208 closed<br>202 opened | 19 | Doubtful | Trouble started when operator opened line switch 206 by mistake. A flashover then developed on the 44-kv. bus between transformers and line switch which flashed over 2 strings of 5-O.B. suspension unit insulators supporting 44-kv bus. A short circuit to ground and from phase to phase developed. Switch #208 closed and trouble was cleared by switch 202 on low tension side of transformer bank. Although relays cleared trouble o. k. the action of the Petersen coil is considered doubtful as trouble did not start until after the line switch was opened. Line was out 1 hour and 19 minutes. |
| July 9 | | | | | 9 | | Recorded at 4:15 a. m. when switch 206 was opened to obtain clearance to work on transformer bank. Line remained charged from Montgomery Steam Plant. |
| | | | | | 5 | | Recorded at 3:20 p. m. when line switch was closed and Lock 12 paralleled with Montgomery Steam Plant. |

TABLE I (Continued)

| Date | Flashover to ground | Solid grounds | Phase-to-phase short circuits | Automatic switch operations | Reactor current amperes | Operation | Nature of trouble and remarks |
|---|---|---|---|---|---|---|---|
| July 11 | 6:28 p.m. | | | | 6 | | Weather cloudy. No outage or surge. |
| July 12 | | 7:56 a.m. | | #208 closed<br>206 opened | 16 | Correct | A tree fell on Mitchell Dam line bringing all three phases to ground. The four additional operations were obtained when line was plugged four times to sectionalize line in locating the trouble. Line was out 47 minutes. |
| | | 7:58 p.m. | | 208 closed<br>206 opened | 25 | Correct | |
| | | 8:00 a.m. | | 208 closed<br>206 opened | 25 | Correct | |
| | | 8:12 a.m. | | 208 closed<br>206 opened | 25 | Correct | |
| | | 8:18 a.m. | | 208 closed<br>206 opened | 26 | Correct | |
| July 12 | | | | | 11 | | Recorded when 206 was opened by hand prior to switching Mitchell Dam back on line. |
| July 13 | 12:18 p.m. | | | | 6 | Correct | Lightning at Montgomery. No outage or surge. |
| | 12:25 p.m. | | | | 6 | Correct | " " " " " " " |
| July 14 | | | 2:01 p.m. | 206 opened | 11 | Correct | Lightning. Voltage surged from 118 to 99 volts. Grounding switch 208 did not close. Line switch 206 reclosed o. k. after 2 minutes interval. Trouble was either phase-to-phase short circuit and the 11 ampere reactor current was the result of 206 opening, or trouble started as flashover to ground and developed into a phase-to-phase short circuit. |
| July 16 | | 1:34 a.m. | | 208 closed<br>206 opened | 18 | Correct | Failure of Potential Transformer Bushing at Vida causing dead ground on system. Operation repeated three times while plugging line and sectionalizing for trouble. Reactor current each time rose to 19 amperes. Line was out 32 minutes. |
| | | 1:36 a.m. | | 208 closed<br>202 opened | 19 | Correct | |
| | | 1:45 a.m. | | 208 closed<br>202 opened | 19 | Correct | |
| | | 1:47 a.m. | | 208 closed<br>202 opened | 21 | Correct | |
| July 16 | | | | | 6 | | Recorded at 4:06 a. m. when line switch 206 was opened by hand to obtain clearance on the line. |
| | 1:35 p.m. | | | | 5 | Correct | Weather cloudy. No outage or surge. |
| | 1:47 p.m. | | | | 4 | Correct | " " " " " " |
| July 18 | 1:55 p.m. | | | | 5 | Correct | Weather fair. No outage or surge. |
| July 18 | 2:00 p.m. | | | | 5 | Correct | " " " " " " |
| July 19 | 4:28 p.m. | | | | 11 | Correct | Weather stormy. No outage or surge. |
| July 23 | 12:20 p.m. | | | | 4 | Correct | Weather cloudy. " " " " |
| July 24 | 10:15 a.m. | | | | 5 | Correct | " " " " " " |
| July 26 | | | | | 8 | | At 6:30 a. m. Mitchell Dam operator reported that they were only receiving single-phase power. The chart showed a reactor current of 3 amperes which held on until 7:00 a. m. when switch 1802 was opened by hand when a current of 8 amperes was recorded due to switching. Upon patrolling line, a lug on a test loop was found burned in two and remaining in the clear but opening the line. |
| | 1:40 p.m. | | | | 6 | Correct | Lightning. No outage or surge. |
| | 2:05 p.m. | | | | 6 | Correct | " " " " " |
| July 27 | | | 5:28 p.m. | 1802 opened | 7 | Correct | Stormy. Started as a phase short circuit, which caused #1 phase conductor to burn in two and fall on ground on Mitchell Dam line at pole 98. Line was plugged back four times in sectionalizing for trouble. At 5:55 p. m. it was decided to operate with the one phase grounded with Petersen coil in service. Grounding switch was blocked so it couldn't close and short out the coil. At 6:12 p. m. a bushing failed on switch 1802 due, no doubt to full line voltage having been imposed on the two ungrounded phases. The Mitchell Dam line was then taken out of service. |
| | | 5:32 p.m. | | 208 closed<br>1802 opened | 22 | " | |
| | | 5:32½ p.m. | | 208 closed<br>1802 opened | 22 | " | |
| | | 5:33 p.m. | | 208 closed<br>1802 opened | 22 | " | |
| | | 5:33½ p.m. | | 208 closed<br>1802 opened | 22 | " | |
| July 27 | | 10:40 p.m. | | 208 closed<br>1802 opened | 22 | " | When Mitchell Dam was closed back in after above switch trouble was repaired, it again opened automatically. This time a line conductor (phase 2) was found burned in two and on the ground at pole #98. This is the same place where #1 phase burned in two at 5:32 p. m. Conductor on Phase #2 was evidently badly burned on the line to line short at 5:28 p. m. |
| July 28 | 2:10 p.m. | | | | 9 | " | Lightning. No outage or surge. |
| | 2:30 p.m. | | | | 5 | " | " " " " " |
| July 30 | | | | | 6 | | Recorded at 10:50 a. m. while switching was being done at Vida. |
| July 31 | | | | | 5 | | Recorded at 11:10 a. m. when #1802 was opened by hand. Current held on until 1802 was closed again at 11:32 a. m. |
| | | | 12:12 p.m. | 206 opened | 5 | " | Lightning. Voltage surged from 114 to 103 volts. Probably a phase-to-phase short circuit as 208 did not close. Reactor current probably due to opening of 206. Switch 206 closed back in o. k. after interval of 2 minutes. |
| | | | 1:28 p.m. | 1802 opened | 6 | " | Lightning. Voltage surged from 115 to 110 volts. Grounding switch 208 did not close, therefore, probably a phase-to-phase short circuit. Reactor current probably due to opening of switch 1802. Line was closed back in o. k. 12 minutes later. |
| | | | | | 5 | | Recorded at 1:40 p. m. when 1802 was closed back in. |

TABLE I (Continued)

| Date | Flashover to ground | Solid grounds | Phase-to phase short circuits | Automatic switch operations | Reactor current amperes | Operation | Nature of trouble and remarks |
|---|---|---|---|---|---|---|---|
| July 31 | | | 1:50 p.m. | 1802 opened | 9 | Correct | Lightning. Voltage surged from 120 to 108 volts. Grounding switch 208 did not close, therefore, probably a phase-to-phase short circuit. Line closed back in o. k. 20 minutes later. This time taken by operator to inspect switch. |
| | | | 1:59 p.m. | 1812 opened | 11 | " | Lightning. Grounding switch 208 did not close. Probably phase-to-phase short circuit. Line was closed back in o. k. one minute later. |
| Aug. 1 | | | | | 5 | | Recorded at 11:15 a. m. when switch 1802 was opened for clearance. Reactor current held on at 5 amperes until 1802 was closed back in at 12:05 p. m. |
| | 12:28 p.m. | | | | 6 | Correct | Weather fair. No outage or surge. |
| Aug. 2 | | | | | 5 | | Recorded at 10:55 a. m. when switch 1802 was opened for clearance and held on until 1802 was closed again at 11:35 a. m. |
| | 8:48 p.m. | | | | 5 | Correct | Lightning. No outage or surge. |
| | 8:55 p.m. | | | | 5 | Correct | " " " " " |
| | 9:05 p.m. | | | | 5 | Correct | " " " " " |
| Aug. 3 | | | | | 5 | | Recorded at 11:00 a. m. when switch 1802 was opened for clearance. Current held on at 5 amperes until 12:00 Noon when 1802 was closed back in. |
| Aug. 5 | 10:10 a.m. | | | | 5 | Correct | Weather fair. No outage or surge. |
| Aug. 8 | | 4:55 p.m. | | 208 closed<br>202 opened | 24 | Faulty | Lightning. Switch 206 failed to trip due to mechanical trouble. Switch 206 was opened by hand and line charged from Montgomery Steam Plant and tested o. k. |
| | | | | | 9 | | Recorded at 7:50 p. m. when 206 was closed back in. |
| Aug. 9 | 1:42 p.m. | | | | 5 | Correct | Weather fair. No outage or surge. |
| Aug. 10 | 10:40 a.m. | | | | 3 | Correct | " " " " " " |
| | 11:20 a.m. | | | | 3 | Correct | " " " " " " |
| Aug. 12 | 10:10 p.m. | | | | 5 | Correct | |
| | 10:20 p.m. | | | | 4 | Correct | |
| | 10:30 p.m. | | | | 5 | Correct | Weather cloudy. No outage or surge. |
| | 10:40 p.m. | | | | 4 | Correct | |
| | 11:10 p.m. | | | | 3 | Correct | |
| Aug. 14 | 1:55 p.m. | | | | 4 | Correct | Weather cloudy. No outage or surge. |
| Aug. 17 | 9:20 a.m. | | | | 5 | Correct | Weather fair. No outage or surge. |
| | 9:55 a.m. | | | | 3 | Correct | " " " " " " |
| Aug. 18 | 6:50 p.m. | | | | 4 | Correct | " " " " " " |
| Aug. 25 | | | 8:35 a.m. | 1802 opened | 4 | Correct | Phase to phase short circuit on low side of transformers at Mitchell Dam. |
| | | 3:18 p.m. | | 208 closed<br>206 opened | 22 | Correct | Tree fell across telephone line causing broken conductors to fall across the 44-kv. line between Vida and Lock 12. |
| | | 3:20 p.m. | | 206 opened<br>208 closed<br>202 opened | 26 | Doubtful | Switch 206 on being closed after above trouble at 3:18 p. m. did not latch and on dropping out a flashover occurred across a five unit string of O. B. Insulators on 44-kv. bus between switch 206 and transformer bank. Grounding switch then closed and trouble was cleared by switch 202 on low side of transformer bank. The O. B. Insulators were meggered after taken down and showed up well, indicating that trouble was not caused by insulator failure. Bus conductor was badly burned. |
| Aug. 26 | | | 12:04 a.m. | 1802 opened | 9 | Correct | Lightning. Grounding switch did not close therefore flashover must have developed into a phase-to-phase short circuit. Switch 1802 was closed back in o. k. |
| Aug. 27 | 11:35 a.m. | | | | 4 | Correct | Weather cloudy. No outage or surge. |
| Sep. 1 | 12:32 p.m. | | | | 5 | Correct | Weather fair. No outage or surge. |
| Sep. 2 | 4:10 p.m. | | | | 6 | Correct | " " " " " " |
| Sep. 4 | 1:00 p.m. | | | | 5 | Correct | " " " " " " |
| Sep. 5 | 3:25 p.m. | | | | 5 | Correct | " " " " " " |
| Sep. 14 | 4:32 p.m. | | | | 18 | Correct | Lightning. " " " " |
| Sep. 17 | | | 1:18 p.m. | 206 opened | 3 | Correct | Rain and lightning. Grounding switch did not close. Voltage surged from 116 to 96 volts. Switch 206 was reclosed o. k. after one minute interval. |
| Sep. 21 | 12:28 p.m. | | | | 6 | Correct | Rain and lightning at Lock 12. No outage or surge. |
| Oct. 7 | 10:54 a.m. | | | | 11 | Correct | Lightning. No outage or surge. |
| Oct. 8 | 6:52 p.m. | | | | 6 | Correct | Weather cloudy. No outage or surge. |
| Oct. 29 | 5:25 p.m. | | | | 5 | Correct | " " " " " " |
| Nov. 5 | 1:35 p.m. | | | | 10 | Correct | Weather fair. " " " " |
| | | The Petersen Coil was out of service from November 16, 1922 to January 13, 1923, while the Transformer Bank was being moved to a new location in the Lock 12 Power House. | | | | | |
| 1923<br>Jan. 14 | | | | | 8 | | Occurred at 8:50 a. m. when switch 1810 was opened to "cut" out Vida-Montgomery line. Current held on at an average of 7 amperes until switch 1810 was reclosed. It is possible that pen may have been stuck. |
| | 6:26 p.m. | | | | 10 | Correct | Cloudy. No outage. Surge 108 to 104 volts. |
| Jan. 19 | 4:20 a.m. | | | | 6 | Correct | Cloudy. No outage or surge. |
| Jan. 23 | | 9:04 a.m. | | 208 closed | 16 | Correct | Raining. No outage or surge. Seems that flashover held on long enough to cause 208 to operate, but cleared before contacts of 208 closed. |

TABLE I (Continued)

| Date | Flashover to ground | Solid grounds | Phase-to-phase short circuits | Automatic switch operations | Reactor current amperes | Operation | Nature of trouble and remarks |
|---|---|---|---|---|---|---|---|
| Feb. 23 | | 6:56 p.m. | | #206 opened<br>208 closed<br>202 opened | 27 | Doubtful | A light surge was noticed on the line one minute earlier—at 6:55 p. m. At 6:56 p. m. a flashover occurred on 44-kv. bus between transformer and line switch #206. One unit of a five unit string of O. B. disk insulators was shattered but not punctured.* Insulators were meggered afterwards and found to be in good condition indicating that trouble was not an insulator failure. The bus conductors near the point of flashover were badly pitted on all three phases indicating that a phase-to-phase short circuit developed. Sequence of switch operations is not known, but as there was no cause for line switch 206 to open on bus trouble, it is thought that 206 opened first on some initial case of line trouble, as indicated by surge at 6:55 p. m. Then due to perhaps a switching transient, the bus flashed over and this secondary trouble was then cleared by the low side transformer switch #202. It is thought that grounding switch #208 did not close until after the 44-kv. bus trouble developed.<br>The line was patrolled afterwards, but no evidence of trouble was found. Line was closed back in o. k. 1 hour and 26 minutes later. |

*This unit was next to the bus conductor.

TABLE II
SUMMARY OF PETERSEN COIL OPERATIONS

| | Flashover Indications | | | | Line Trouble | | Trans. Trouble | | Cir. Break. Tble. | | Bus Trouble | | Other Indications | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | Under 6 amperes | Over 6 amperes | Faulty. Line Sw opened | 208 closed but no inter-ruption | Phase to ground | Phase to phase | Phase to ground | Phase to phase | Solid ground | Phase to phase | Solid ground | Phase to phase | Open-ing switches | Closing switches |
| 1921 | | | | | | | | | | | | | | |
| Nov. | .. | .. | .. | .. | .. | .. | .. | 1 | | | | | | .. |
| Dec. | .. | 6 | 1 | 6 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1 |
| 1922 | | | | | | | | | | | | | | |
| Jan. | .. | 1 | .. | .. | .. | .. | 1 | .. | .. | .. | .. | .. | .. | .. |
| Feb. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| Mar. | .. | 2 | .. | .. | .. | 2 | .. | .. | .. | .. | .. | .. | 1 | 1 |
| Apr. | 18 | 6 | .. | .. | .. | 1 | .. | .. | .. | .. | .. | .. | .. | .. |
| May | 53 | 3 | .. | .. | .. | 1 | .. | .. | .. | .. | .. | .. | 2 | 1 |
| June | 17 | 3 | .. | .. | .. | 4 | .. | .. | .. | .. | .. | .. | .. | .. |
| July | 11 | 8 | .. | .. | 3 | 5 | 1 | .. | 1 | 1 | 1 | .. | 6 | 4 |
| Aug. | 18 | 1 | 1 | .. | 1 | 1 | .. | 1 | .. | .. | 1 | .. | 2 | 1 |
| Sep. | 3 | 3 | .. | .. | .. | 1 | .. | .. | .. | .. | .. | .. | .. | .. |
| Oct. | 1 | 2 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| Nov. | .. | 1 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| Dec. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 1923 | | | | | | | | | | | | | | |
| Jan. | .. | 2 | .. | 1 | 1 | .. | .. | .. | .. | .. | .. | .. | 1 | .. |
| Feb. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1 | .. | .. | .. |
| Total | 121 | 38 | 2 | 7 | 5 | 15 | 2 | 2 | 1 | 1 | 3 | .. | 12 | 8 |

failure of all three poles of the oil circuit breaker to open or close simultaneously, thereby causing the system neutral to shift somewhat due to a momentary unbalanced electrostatic condition on the line. It is proposed to make further tests to verify this point.

## Grounded Phase Operation

As noted in Table I operation with one phase conductor on the ground was attempted on July 27, 1922, in the effort to continue service until the line could be more conveniently taken out for repairs later on. After 17 minutes of grounded phase operation a switch bushing failed on one of the ungrounded phases, due no doubt to the imposition of full line voltage to ground on these phases. Our experience in this one case indicates that, although the Petersen coil may prevent arcing grounds on grounded phase operations, it is hardly safe to take the risk, as the imposition of full-line voltage to ground on the ungrounded phase for a considerable length of time will tend only to aggravate the trouble.

The Petersen coil was designed for continuous service to take care of possible grounded phase operations in emergency. With grounded phase operation eliminated, the Petersen coil need only have approximately a 2-minute rating, and could be built at a cost much less than that of a continuously rated coil.

## Comparison of Operation with and without the Petersen Coil

In the ultimate analysis the value of the Petersen coil will be determined by its service record, and no better conclusions can be drawn than by a direct comparison of the interruption records of similar

periods and conditions, with and without the Petersen coil in service.

For such a comparison we have taken the period, January through September 1921, as covered by Table III before the Petersen coil was installed, and a corresponding period in 1922, as covered by Table IV, when the Petersen coil was in service.

In 1921 there were 43 interruptions due to lightning causing the line to be out of service a total of 230 minutes.

TABLE III

INTERRUPTIONS TO LOCK 12-VIDA LINE—1921

(Petersen Coil not in Service)

(Exclusive of interruptions due to trouble on other parts of Alabama Power Company's system)

| Month | Lightning | | Transformers | | Conductor | | Oil Switch | | Unknown | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No cases | Time out in minutes | No cases | Time out in minutes | No cases | Time out in minutes | No cases | Time out in minutes | No cases | Time out in minutes | No cases | Time out in minutes |
| January | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| February | 1 | 3 | .. | .. | .. | .. | .. | .. | .. | .. | 1 | 3 |
| March | 4 | 9 | .. | .. | .. | .. | .. | .. | .. | .. | 4 | 9 |
| April | 1 | 3 | .. | .. | .. | .. | .. | .. | .. | .. | 1 | 3 |
| May | 2 | 28 | .. | .. | .. | .. | .. | .. | .. | .. | 2 | 28 |
| June | 3 | 18 | .. | .. | .. | .. | .. | .. | .. | .. | 3 | 18 |
| July | 13 | 121 | .. | .. | .. | .. | .. | .. | .. | .. | 13 | 121 |
| August | 5 | 20 | .. | .. | .. | .. | .. | .. | .. | .. | 5 | 20 |
| September | 14 | 28 | .. | .. | .. | .. | 1 | 72 | 1 | 2 | 16 | 102 |
| Total | 43 | 230 | .. | .. | .. | .. | 1 | 72 | 1 | 2 | 45 | 304 |

TABLE IV

INTERRUPTIONS TO LOCK 12-VIDA LINE—1922

(Petersen Coil in Service)

(Exclusive of interruptions due to trouble on other parts of Alabama Power Company's system)

| Month | Lightning | | Transformers | | Conductor | | Insulator | | Oil Switch | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No cases | Time out in minutes | No cases | Time out in minutes | No cases | Time out in minutes | No cases | Time out in minutes | No cases | Time out in minutes | No cases | Time out in minutes |
| January | .. | .. | 1 | 343 | .. | .. | .. | .. | .. | .. | 1 | 343 |
| February | .. | .. | .. | .. | .. | .. | .. | .. | — | .. | .. | .. |
| March | .. | .. | .. | .. | 1 | 2 | 10 | 88 | .. | .. | 11 | 90 |
| April | 1 | 2 | .. | .. | .. | .. | .. | .. | .. | .. | 1 | 2 |
| May | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| June | 2 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | 2 | 4 |
| July | 3 | 6 | 1 | 13 | 1 | 47 | 1 | 79 | 2 | 11 | 8 | 156 |
| August | .. | .. | .. | .. | .. | .. | 1 | 62 | 1 | 172 | 2 | 234 |
| September | 1 | 2 | .. | .. | .. | .. | .. | .. | .. | .. | 1 | 2 |
| Total | 7 | 14 | 2 | 356 | 2 | 49 | 12 | 229 | 3 | 183 | 26 | 831 |

In 1922 there were only 7 cases of interruptions due to lightning, or a reduction of 83.5 per cent, with the line out of service a total of only 14 minutes, or a reduction of 94 per cent.

In 1922 there were, however, more cases of trouble due to other causes, but that the majority of them were independent of the Petersen coil performance can be shown as follows:

*Transformers.* The interruption of 343 minutes due to transformer trouble occurred on January 21 while short-circuit tests were being made at Lock 12. A transformer failed due to short-circuit stresses. The Petersen coil was out of service during the tests.

*Conductors.* The interruptions of 2 minutes and 47 minutes respectively in March and July charged to conductors, was caused in each case by a tree falling down on the line.

*Insulators.* The ten interruptions in March all occurred on the 7th when an insulator pulled loose from its pin and swung into the phase above. This resulted in a phase-to-phase short circuit and consequently gave no indications on the Petersen coil chart for this day. The interruptions of 79 and 62 minutes respectively in July and August were due to insulator flashovers on the 44 kv. bus at Lock 12. These flashovers seemed to develop after the line switch opened, so there is some doubt as to the origin of the trouble.

*Oil Switches.* The interruptions charged to Oil Switches in July and August were all due to mechanical trouble in the switch mechanisms.

## Conclusions

The Petersen coil has decidedly reduced the number of interruptions due to insulator flashovers during lightning storms. It has, however, produced several actions which need further investigation, namely, the bus insulator flashovers which occurred when line switching was done with the Petersen coil in service. It is proposed to make further tests on such actions to see if high voltages are actually produced.

Points, which operating experience with the Petersen coil has thus far proven are:

1. All insulator pins should be grounded in order to secure the best positive action on the coil.

2. All switching, both hand and automatic should be done with the coil out of service—namely, with the system neutral solidly grounded.

3. Grounded phase operation is not advisable.

# Operating Experience with Current-Limiting Reactors


BY N. L. POLLARD

Fellow, A. I. E. E.

Public Service Production Company, Newark, N. J.



***Review of the subject.***—*This paper describes the troubles experienced with different types of current-limiting reactors installed on the Public Service Electric Company's system. Many of these failures are attributed to poor mechanical construction.*

*The author states that the experience gained has resulted in much better designs. The conclusion is reached that if the present day reactors are properly chosen with regard to thermal capacity they are very reliable.*


CONTENTS



---

THE purpose of this paper is to give an account of the operating experience with current-limiting reactors installed on the system of the Public Service Electric Company of New Jersey.

## Description of System

The above-mentioned system is composed of two large sections: The Southern Division, which includes the territory between Camden and Trenton; and the Northern Division, which comprises the northeastern part of New Jersey. Since current-limiting reactors at the present time are used only in the Northern Division, merely this part of the system will be described.

The 13,200-volt, 25-cycle system is comparatively small, as it includes only 35,200 kw. generating capacity. Since this system has reactors only on the generator leads in the Marion Station, and because all the apparatus will be replaced by 60-cycle machines within the next few years, no further mention will be made of it with the exception of a brief description of the reactors later.

The bulk of the 60-cycle current is generated at Marion and Essex Stations located about three and one-half miles apart and connected together by means of five 13,200-volt tie lines. The Marion capacity is 60,500 kv-a. and Essex 85,000 kv-a. In addition there are five other smaller stations with a combined capacity of 44,500 kv-a. feeding into the system at different points, giving this Division a total capacity of 190,000 kv-a.

The 60-cycle transmission system in the Northern

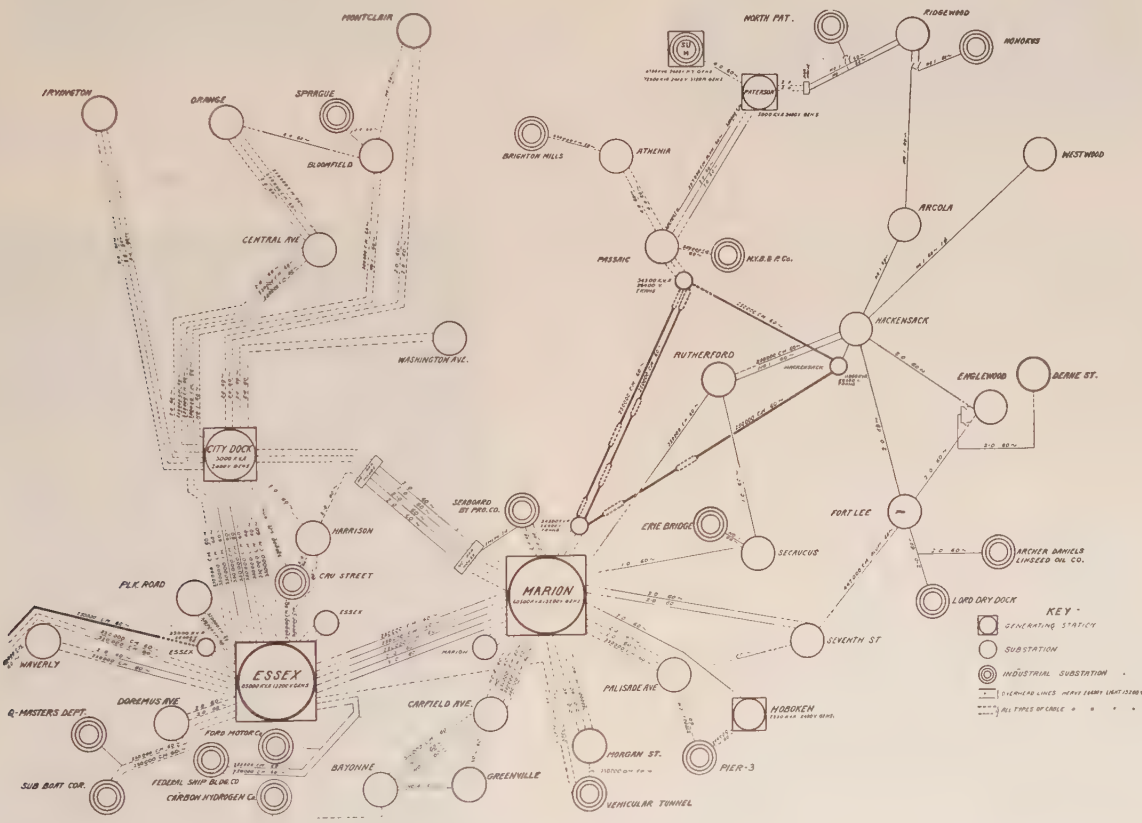



Fig. 1

---

*Presented at the Spring Convention of the A. I. E. E., Pittsburgh, Pa., April 24-26, 1923.*

Division consists of 580 miles of 13,200-volt lines and 121 miles of 26,400-volt lines. Of the 13,200-volt lines, 322 miles are overhead and 258 miles underground; of the 26,400-volt lines, 97 miles are overhead and 24 miles underground. Fig. 1 is a one-line diagram of the 60-cycle system in the north section of the Northern Division, and Fig. 2 shows the south section of this division.

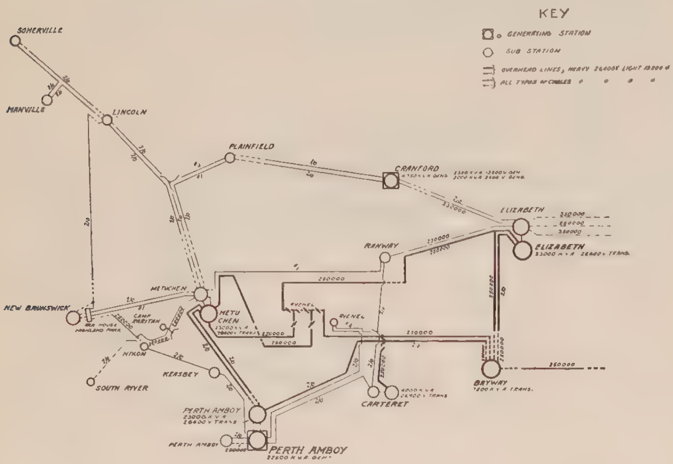



Fig. 2

These two sections are tied together with a 26,400-volt line between Essex and Bayway, and with several 13,200-volt lines between Essex and Elizabeth.

## Need for Reactors

The need for current-limiting reactors was first brought to our attention in 1912, when the oil circuit breakers commenced to fail on the 25-cycle system in

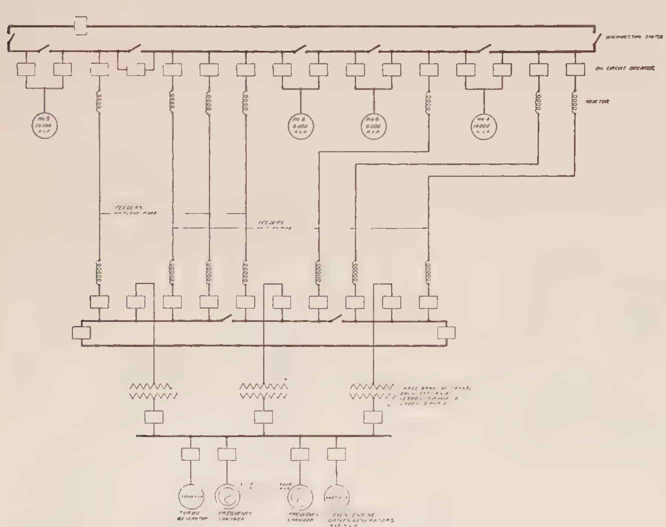


Fig. 3

the Marion Station. The reactance of these turbo-generators was only 3 per cent, so in order to relieve the excessive strains on the equipment, 3 per cent reactance coils were inserted in the generator leads of each machine. (Fig. 5 shows one of these reactors.) This relieved the 25-cycle system to a great extent from oil circuit breaker and other troubles.

In 1914 the 60-cycle system had grown to such an extent that the oil circuit breakers and other equipment were failing frequently. As a result of these failures we decided to install 5 per cent reactors on all radial 13,200-volt feeders, 2½ per cent reactors on all tie feeders, and aluminum cell arresters on the feeder side

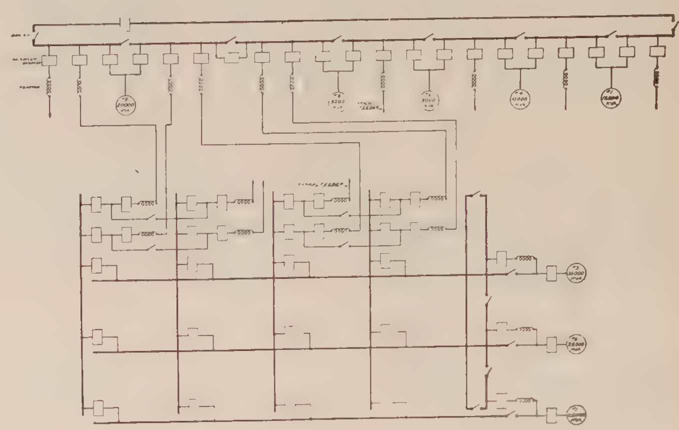


Fig. 4

of all reactors whether the feeder was overhead or underground. This required a total of 29 sets of reactors, all of which were purchased for 5 per cent reactance with a 2½ per cent tap so that they could be used on either type of feeder. Essex Station was not built at

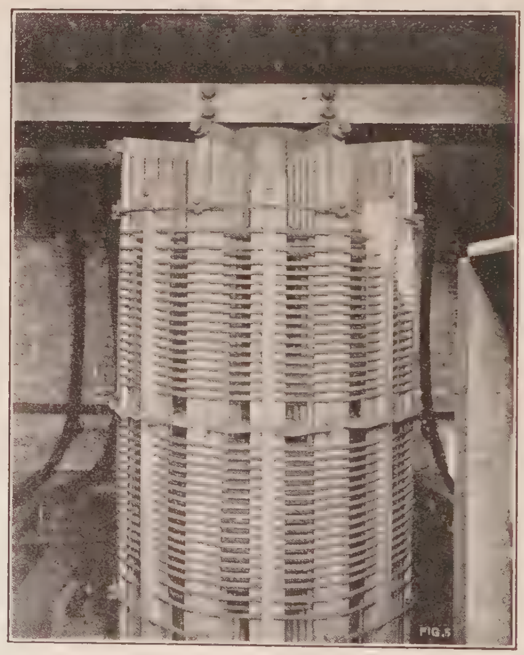


Fig. 5

this time. The seven tie feeders between Marion and City Dock Stations were equipped with 2½ per cent reactors at each end. It was necessary to install reactors at both ends in order to allow selective action of the balanced relays which were installed on these feeders. Before purchasing the reactors we sent a man to the factory to witness tests, which included both high

voltage and high frequency, and we were assured by the manufacturer's engineers that these reactors were so well designed that they would stand up under any operating condition. The factory tests seemed to prove their statements.

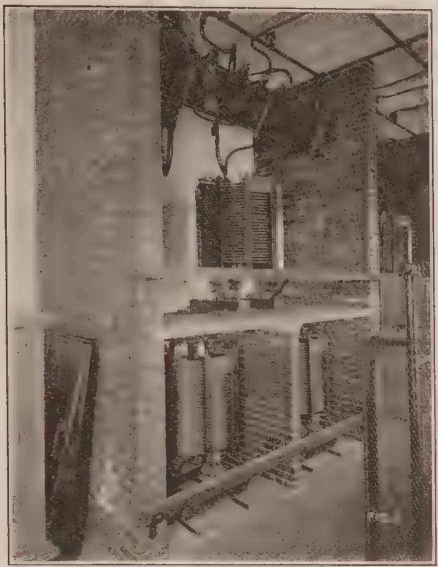


FIG. 6

Fig. 3 shows the Marion and City Dock busses and tie lines at the time these 60-cycle reactors were installed. Fig. 6 illustrates a typical installation at Marion.

Contrary to expectation, we experienced considerable

FIG. 7

trouble with this first installation of 60-cycle reactors; therefore we decided to install an entirely different type in 1915 in the new Essex Station. These reactors are shown in Figs. 7 and 8. The first sixteen sets (Fig. 7) proved very satisfactory, but the second installment of ten sets (Fig. 8) has been a constant source of trouble.

Fig. 4 shows the Marion and Essex busses and tie lines after these reactors were installed.

From 1917 to the present time we have installed 18 sets of reactors of the types shown in Figs. 9, 10 and 11,

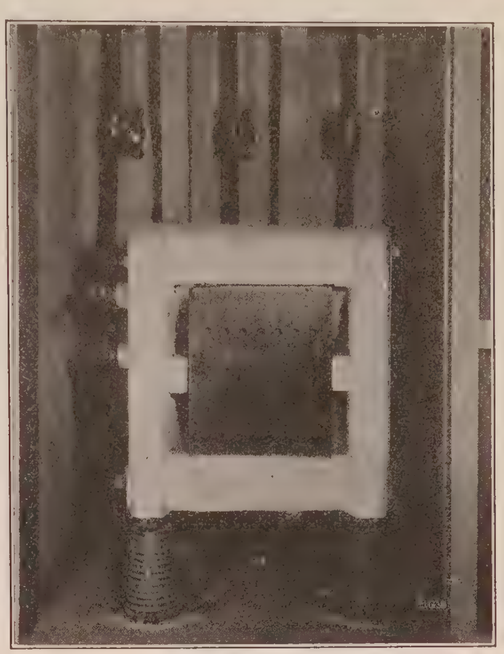


FIG. 8

and with two exceptions these have given very satisfactory service.

Table I gives the rating, type and number of reactors installed to date at Marion, Essex, and City Dock, including the twelve 25-cycle generator reactors at Marion.

TABLE I.
REACTOR INSTALLATIONS

| Group | Illustration | Number of Reactors (All 1-phase) | No. of Sets | Amperes | Per cent | Kv-a. | Year Installed |
|---|---|---|---|---|---|---|---|
| A | Fig. 5 | 6 | 2 | 220 | 3 | 50. | 1913 |
| | | 6 | 2 | 395 | 3 | 90. | 1913 |
| B | Fig. 6 | 72 | 24 | 175 | 5 | 66.8 | 1914 |
| | | 12 | 4 | 250 | 5 | 95.3 | 1914 |
| | | 3 | 1 | 350 | 5 | 133.3 | 1914 |
| C | Fig. 7 | 6 | 2 | 150 | 5 | 57.1 | 1915 |
| | | 9 | 3 | 175 | 5 | 66.8 | 1915 |
| | | 12 | 4 | 250 | 5 | 95.3 | 1915 |
| | | 21 | 7 | 350 | 5 | 133.3 | 1915 |
| D | Fig. 8 | 6 | 2 | 550 | 2 | 83.9 | 1917 |
| | | 9 | 3 | 250 | 5 | 95.3 | 1917 |
| | | 15 | 5 | 350 | 5 | 133.3 | 1917 |
| E | Figs. 9, 10, 11 | 6 | 2 | 545 | 1.5 | 63. | 1917 |
| | | 6 | 2 | 175 | 5 | 66.8 | 1919–20 |
| | | 3 | 1 | 765 | 1.5 | 88. | 1917 |
| | | 9 | 3 | 250 | 5 | 95.3 | 1919–20 |
| | | 18 | 6 | 350 | 5 | 133.3 | 1919–21 |
| | | 12 | 4 | 300 | 8 | 183. | 1918 |

Table II gives a list of the different kinds of failures and the reactor-years per failure.

TABLE II.
REACTOR FAILURES

| Group | Illustration | Nature of Failure: Turns Short Circuited | Arced Over | Miscellaneous | Complete Failure | Total Number of Failures | Reactor-Years: Total | Per Failure | Per Complete Failure |
|---|---|---|---|---|---|---|---|---|---|
| A | Fig. 5 | 2 | .. | .. | .. | 2 | 120 | 60 | .. |
| B | Fig. 6 | 2 | 6 | 5 | 11 | 24 | 676 | 28.1 | 61.4 |
| C | Fig. 7 | 2 | .. | .. | .. | 2 | 408 | 204 | .. |
| D | Fig. 8 | 5 | 4 | 8 | 8 | 25 | 165 | 6.6 | 20.6 |
| E | Figs. 9, 10, and 11 | .. | .. | 3 | .. | 3 | 213 | 71 | .. |

## Comparison of Different Types of Reactors

For the purpose of comparing the different coils from an operating viewpoint, they have been divided into groups A, B, C, D and E, each group representing a definite type of make and a certain date of installation.

*Group A, Fig. 5.* Four sets of coils of this type were installed on the 25-cycle generator leads in 1913 and have given very satisfactory service with only two cases of trouble during the 10 years of operation. The first failure was caused by water getting in the reactor room and grounding one coil. In the second failure the heat of the copper caused the wooden strips supporting the coils to shrink, thus allowing so much slack in the windings that some of the turns became short-circuited. The trouble was remedied by overhauling the coils and drawing the conductors tightly over the wooden strips.

*Group B, Fig. 6.* This group represents a total of 29 sets of 5 per cent coils with a 2½ per cent tap, installed at Marion and City Dock in 1914. As can be seen from Fig. 6, these coils are made of stranded conductors wound in parallel layers with notched strips of specially prepared moulded non-inflammable material between the layers. Non-magnetic castings are placed at the top and bottom of the coils, and the different sections are held together by brass tie rods. All the terminals are located at the top of the reactor.

The numerous cases of short-circuited and completely wrecked coils indicated that they were not sufficiently braced, and did not have the proper clearance between layers and between coils and metal tie rods to withstand the severe operating conditions. Failures in most cases occurred between the outer turn of either the top or bottom coil and one of the brass tie rods.

In this group there have been twenty-four failures listed as follows:

2 cases of short-circuiting of turns.
6 cases of arcing from top to bottom.
3 cases of lugs burning off.
2 cases of winding burning open.
11 cases of complete failure.

After these reactors proved faulty, the manufacturer discontinued building this type and designed a new coil with the following improvements: Greater spacing between layers; wood tie rods instead of brass; heavier supports; insulators with a higher flashover; terminals brought out one on top and one on bottom.

From certain operating experience reported by various companies it would seem that the above improvements have eliminated most, if not all, of the previous faults of this make of reactor.

*Group C, Fig. 7.* Sixteen sets of reactors of this type were installed at Essex in 1915, nine of which were placed on tie feeders and the remaining seven sets on radial feeders.

These coils are 5 per cent with a 2½ per cent tap and are series-wound similar to Group B except that insulated cable is used. Their axis is vertical and the coils are partially enclosed by porcelain bricks with soapstone slabs at the top and bottom, held together by brass tie rods.

In this group there have been only two failures: The first occurred after two years of service when one of the coils arced from top to bottom; the second occurred when several turns short-circuited in another coil after three years of service. Both coils were repaired and have not given any further trouble.

*Group D, Fig. 8.* This group, which differs in design from Group C, consists of 10 sets of coils installed at Essex in 1917. These coils have two sections connected in series, each section being made up of six pancake coils in parallel. One section has a diameter approximately three inches less than the other. The coils have a horizontal axis and are partially enclosed with porcelain bricks. They are built for 5 per cent reactance and have a 2½ per cent tap.

Within three months after the installation of these reactors, three total failures occurred. In each case the coil caught fire from the arcing between a number of turns, and before the fire could be extinguished the coils were badly burned, loosened, distorted, and partially wrecked. Immediately following these cases of failure the coils were returned to the manufacturer for rebuilding and reinforcing. After the third case of trouble it was decided to return the entire ten sets for rebuilding, as it had been fully demonstrated that the coils were mechanically weak. The rebuilding and reinforcing consisted in substituting brass holding rods for the wooden rods and a general strengthening of the coils.

After the coils had been rebuilt and re-installed, they continued to give unsatisfactory service in that some of them operated very noisily at normal load, and at times of cable failures or insulator flashovers the brick-work construction of the coils was often loosened and the insulators broken. On account of the frequency of these failures it was decided to return the entire ten sets of coils to the factory for a second rebuilding. We recommended to the manufacturer that a filler more durable than "petrite" be used and also that special porcelain brick be used instead of wood for bracing that

part of the coil having the smaller diameter. After it was found that this second rebuilding produced very little, if any, improvement, we decided to rebuild six of these coils ourselves. Instead of porcelain brick we used cast concrete corners so as to obtain a tight fit

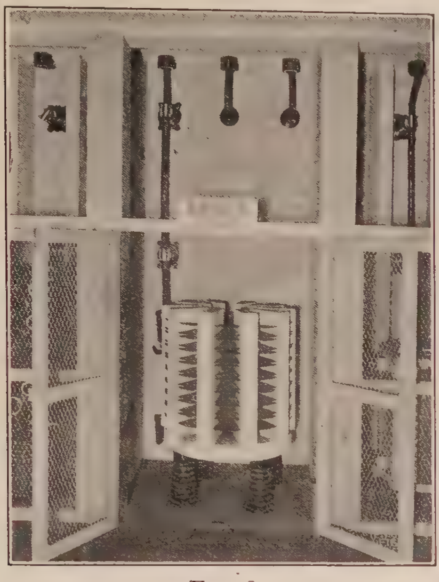


Fig. 9

against both sets of pancakes. To secure ample insulation a 1/16-in. layer of sheet mica was placed between the coils and the concrete.

At first it seemed that this method of rebuilding was

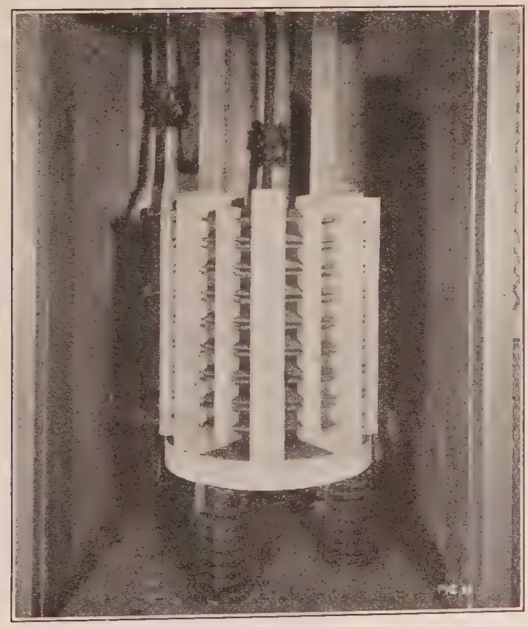


Fig. 10

a success, but after a few months' service several of these coils became noisy again. On account of these reactors having windings of two different diameters, it is very difficult to make them strong enough mechanically to stand up under short-circuit conditions.

In addition to seventeen electrical failures, there have been several cases where the coils became noisy and had to be removed from service for mechanical repairs. At present, whenever a coil commences to become noisy, it is taken out of service and scrapped. It is needless to

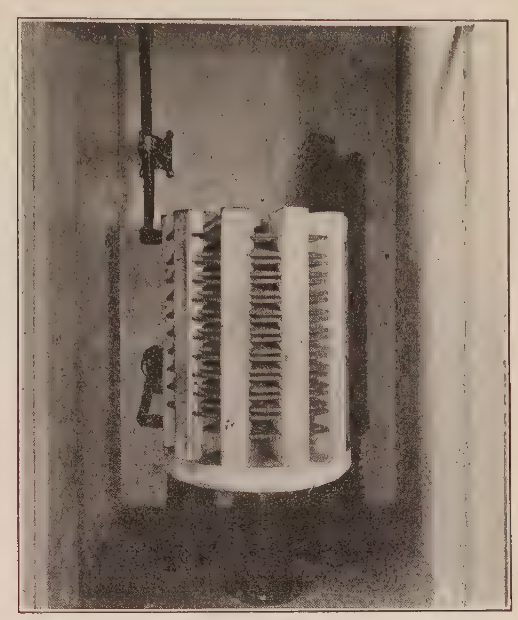


Fig. 11

say that this design of reactor is not being perpetuated.

*Group E, Figs. 9, 10, and 11.* This group represents a total of 18 sets of reactors, part of which were built for 5 per cent with a $2\frac{1}{2}$ per cent tap, and the remainder

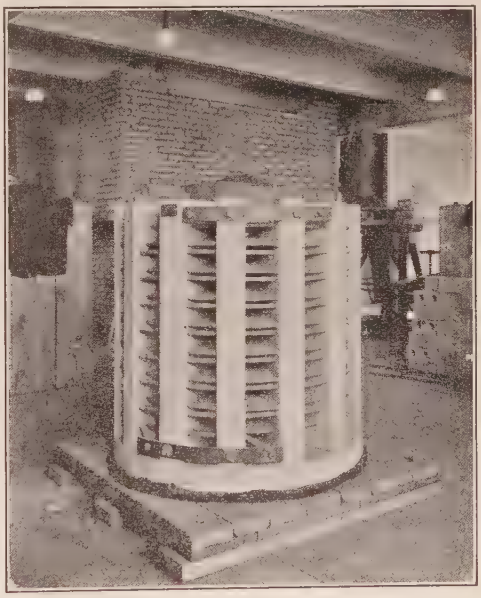


Fig. 12

were $1\frac{1}{2}$ per cent coils for use on the generator tie bus. They were installed at different times between 1917 and 1920.

About one year after the first installation there were two instances of trouble: The first occurred on a tie

feeder and resulted in the short-circuiting of two reactors; the second occurred on another tie feeder and caused the concrete to crack on one of the coils. These demonstrations were sufficient to prove that the concrete supports were not close enough to prevent the conductors from pulling together and causing short-circuiting of the turns during times of trouble on the transmission lines.

After an investigation by the manufacturer it was decided to return part of these reactors to the factory for reinforcing, the decision applying only to those coils which were to be used on the 2½ per cent tap. Fig. 10 illustrates one of the coils after it had been reinforced with additional concrete supports half way between the old ones.

The latest type of reactor which we have installed is shown in Fig. 11. This coil is supposed to have all of the necessary characteristics and none of the bad qualities of any of the types previously described. The few of this newer design that were installed have not as yet been in service long enough to demonstrate whether they will stand up under all conditions, but we hope that they will live up to our expectations.

Fig. 12 illustrates a generator tie bus reactor rated at 5 per cent, 545 amperes, 208 kv-a. We have purchased a number of these coils for future installation.

### Conclusions

It has been the opinion among a number of central station engineers that it was unnecessary to install aluminum cell arresters on the feeder side of reactors when the feeders consisted of underground cable. However, we have always felt that the arresters at times of system disturbances acted as relief valves, and since they have almost invariably discharged in cases of disturbances it would appear that they did relieve the system of at least a part of the strain.

As a word of caution it is well to point out the importance of adequate thermal capacity in reactors. From all indications a number of our failures were due to lack of thermal capacity. Since a reactor is essentially a protective device, it should be designed with a copper cross-section in excess of that of any part of the system which it protects, so that an extended period of severe duty will not cause it to fail because of lack of thermal capacity.

In spite of the troubles which we have experienced with reactors, the number of instances in which they functioned properly has far exceeded the cases of failure. Furthermore, the design of present-day reactors has been perfected to such an extent that, if properly chosen with regard to thermal capacity, the modern reactor may be considered as a very reliable piece of apparatus.

---

Scientific Paper No. 471, recently issued by the Bureau of Standards describes various methods of measuring the properties of solid electrical insulating material.

## NOTES FROM THE BUREAU OF STANDARDS

### REVISION OF CIRCULAR ON STANDARDS FOR ELECTRIC SERVICE

Several meetings have been held during the past month to discuss the revision of Circular 56 of the Bureau of Standards on Standards for Electric Service. The Bureau has had the benefit of criticism by members of a committee representing the National Electric Light Association and the Association of Edison Illuminating Companies. A final meeting was held in New York on July 19, and all points have been mutually agreed upon. A new edition of the circular will undoubtedly have the full endorsement of the organizations representing the electric light and power industry.

---

### LINE RADIO COMMUNICATION

A publication giving an introduction to the subject of line radio communication has recently been prepared under the direction of the Chief Signal Officer of the Army with the cooperation of the Bureau of Standards. This pamphlet gives an explanation of how messages are carried to distant points by radio frequency currents directed over ordinary telephone lines or power wires. The fundamental principles of radio and its relation to line radio telegraphy and telephony are discussed. This pamphlet, Signal Corps Radio Communication Pamphlet No. 41, entitled, "Introduction to Line Radio Communication," can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C.

---

### MEASUREMENTS OF VOLTAGE AMPLIFICATION OF AUDIO FREQUENCY AMPLIFIERS

Letter Circular 98, one of the mimeographed series of the Bureau of Standards, entitled, "Some Measurements of Voltage Amplification of Audio Frequency Amplifiers," has just been issued. This circular gives the results of voltage amplification measurements made on 16 audio frequency amplifiers which were on the market during 1921-22. All these amplifiers employed transformer coupling. Measurements were made over a frequency range of 400 to 2100 cycles per second. The amplifiers studied are referred to by arbitrary reference numbers rather than by a statement of the manufacturers' names and model number, the method followed being the same as that in connection with Letter Circular 86 on "Methods of Measuring Voltage Amplification of Amplifiers."

It is believed that the examples given in this report will be of assistance to manufacturers in testing and describing their own products and will thus lead to their improvement. A limited supply of these circulars is available and may be obtained by addressing the radio section of the Bureau of Standards.

# Electrical Loud Speakers

BY A. NYMAN
Associate, A. I. E. E.
Westinghouse Elec. and Mfg. Co.

***Review of the Subject.***—*An electrical loud speaker is a device applied to radiophone reproduction of speech and music.*

*This paper brings out the mechanical and electrical essentials of this device and gives a short description of present-day forms and methods used in developing and testing new types.*

*A technical analysis of one successful form brings out the various factors involved and the means used for achieving satisfactory results. These results are illustrated by appropriate test curves.*

*The paper is a record of results obtained through technical analysis of this apparatus and is intended to direct attention to the necessity of similar analysis continued and extended.*

---

THE popularity of radiophone broadcasting has created a considerable demand for an electrical loud speaker. Electrical loud speakers have been used for a number of years for such purposes as train announcing. However, this type of loud speaker was developed primarily for speech reproduction and as long as it possessed a certain degree of clearness, was considered satisfactory.

The major part of radiophone broadcasting is music and the aesthetic value of music is its vital element. Therefore, music reproduction should be so close to the original as to maintain its aesthetic value.

It has been found that music reproduction requires the presence of notes ranging in frequency from 25 cycles per second to 5000 cycles per second. The quality of reproduction is affected to a large extent by the loudness of individual frequencies; hence, the necessity of bringing in each frequency at a value proportional to the original volume. It can readily be seen that the quality of the pick-up instrument or microphone, as well as the design of the transmitting and receiving systems is of utmost importance.

Apart from the pick-up and transmission, the following essential features pertain to the loud speaker alone:

1. Uniform intensity of sound at all frequencies from 25 cycles to 5000 cycles.

2. Absence of resonance points capable of responding at a frequency different from applied or giving an excessive volume of sound when their frequency is applied.

3. The ability to reproduce a combination of frequencies with a volume of each frequency proportional to the input.

4. Absence of distorting harmonics at any individual frequency applied.

Feature 1 is particularly important in reproducing every kind of sound; for example: A weak or missing range of frequency is noticeable even to an untrained ear. However, if it is near either end of total range, *i.e.*, below 400 or above 3000, an untrained ear may sometimes fail to detect this defect. Similarly an individual missing frequency can be occasionally overlooked. A loud range distorts the quality to a considerable extent and a loud individual note has a very unpleasant blasting effect.

Feature 2, if overlooked is particularly liable to give blasting or an unnatural ring of certain notes. The fundamental may be suppressed and a harmonic of an altogether different pitch come through, possibly considerably louder than the applied note.

Feature 3, dealing with combination of frequencies, is particularly noticeable in speech reproduction. Normal vowel sounds consist of a fundamental of rather small volume and harmonics often much larger than the fundamental. Unless the proportionality is maintained the sound of the voice changes giving the impression of a changed pitch; tenor voice may sound like bass; soprano like contralto, or vice versa. The higher harmonics again determine the individual characteristics of the voice. Thus, in order to recognize a person's voice, the higher harmonics up to the 20th or 30th must be included and kept at their proportional value. What is true of voice is true of most musical instruments. The pitch, or the individuality may appear changed unless a proportionality is maintained.

Feature 4: Certain materials have qualities which give them peculiar forms of vibration. Thus, the vibrations of brass are usually different from aluminum, wood or micarta. This is generally due to a number of harmonics, each modifying the original note. In a loud speaker the pleasing quality and the naturalness of reproduction are dependent to a very great extent on the choice of materials, particularly of the material carrying a large amount of energy of sound.

## Structures of Loud Speakers

A number of structures have been used successfully as loud speakers.

Fig. 1 shows a loud speaker operating on the same principle as an ordinary telephone receiver. It has a thin iron diaphragm held at a small distance from two magnetic pole pieces, which are energized by a permanent magnet and also by two coils, one on each pole piece. The volume that can be obtained from this type of loud speaker is somewhat limited on account of the close spacing between the diaphragm and the pole pieces. Moreover, certain notes are accentuated, due to the resonance of the diaphragm.

Fig. 2 shows a moving coil type of loud speaker. A

*Presented at the Annual Convention of the A. I. E. E. Swampscott, Mass., June 26-29, 1923.*

circular coil is located in a round air-gap, with an iron core in the center. This air-gap is traversed by a strong magnetic field, excited by an inner coil which carries direct current while the circular coil mentioned above carries sound-producing alternating current and is attached to the center of a diaphragm. Very satisfactory results can be obtained with this type of loud speaker.

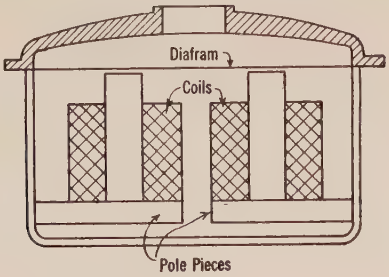



Fig. 1

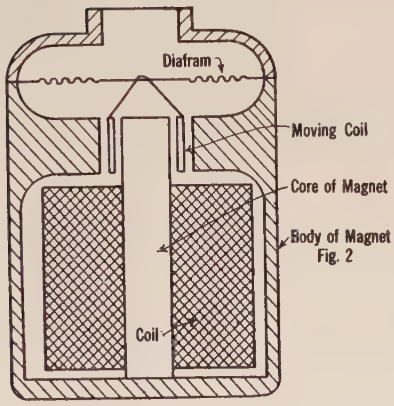



Fig. 2

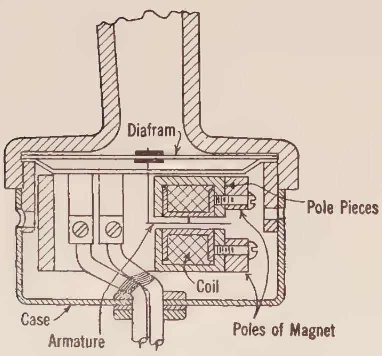



Fig. 3

Fig. 3 shows what may be termed the enclosed armature type. A small iron armature is located in the center of a coil and suspended by two thin piano wires. The coil is surrounded by two U-shaped pole pieces, forming two air-gaps. A permanent magnet produces magnetic flux in these air-gaps. The current in the coil causes diametrically opposite pole pieces to be energized simultaneously, which causes the armature to rock. This rocking is communicated through a thin connecting rod to the center of a diaphragm.

Fig. 4 shows the sound distribution for a loud speaker constructed on this principle. The curve is taken by a method described below. The loudness is fairly uniform over the range. The curve shows the frequency from 100 cycles to 10,000 cycles for abscissa and loudness for ordinate.

Fig. 5 shows the "relay type" loud speaker recently developed. Its construction is similar to that of a

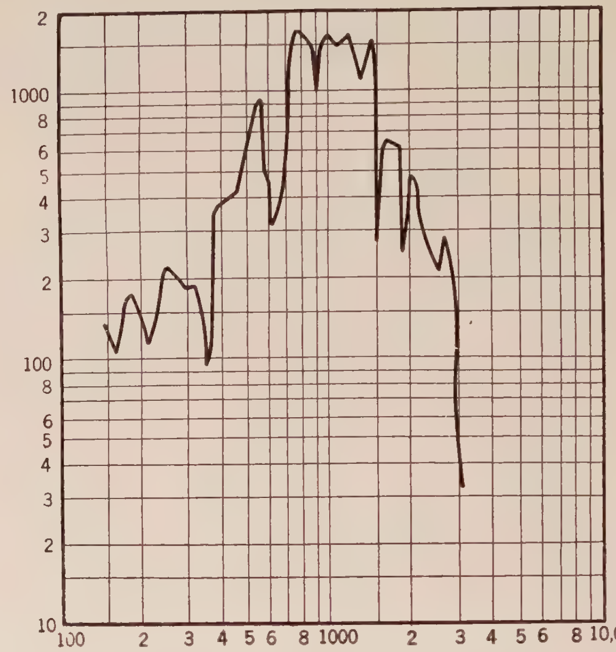



Fig. 4

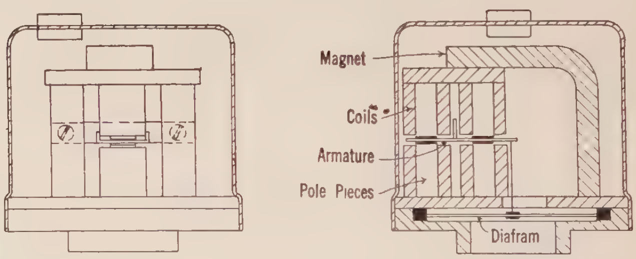



Fig. 5

polarized telegraph relay. A thin iron armature is located between four pole pieces, each carrying a coil. These pole pieces are magnetized by an L-shaped magnet and the coils are connected in such a manner that diametrically opposite pole pieces exert simultaneous attraction. The armature operates through a rod on a corrugated aluminum diaphragm.

Fig. 6 gives a representative curve of this loud speaker. The range is fairly wide, while no part of it is exaggerated in volume.

## Methods of Testing

The four essential features of the loud speaker have been investigated by different test methods, partly dynamical and partly physiological; *i.e.*, depending on aural observations.

Fig. 7 shows a diagram of an oscillator designed to cover a range from 150 to 10,000 cycles. A number of steps of condenser capacity raise the frequency about 50 to 100 per cent while for each step the movement of an inductive coil on and off an iron core gives gradual variations of frequency. Each step of condenser is calibrated for frequency at different coil settings which are indicated on a graduated scale. The coil acts as an inductance and also as a transformer. Operating the set at 20 watts, the amount of power drawn to the loud speaker is small giving good voltage and frequency regulation on load. In order to make the loud speaker circuit equivalent to a tube circuit, a resistance equal to the tube impedance is included in series with the loud speaker. Although the voltage on the oscillator remains fairly constant throughout the whole range, for quantitative measurements, the voltage can be checked at each reading.

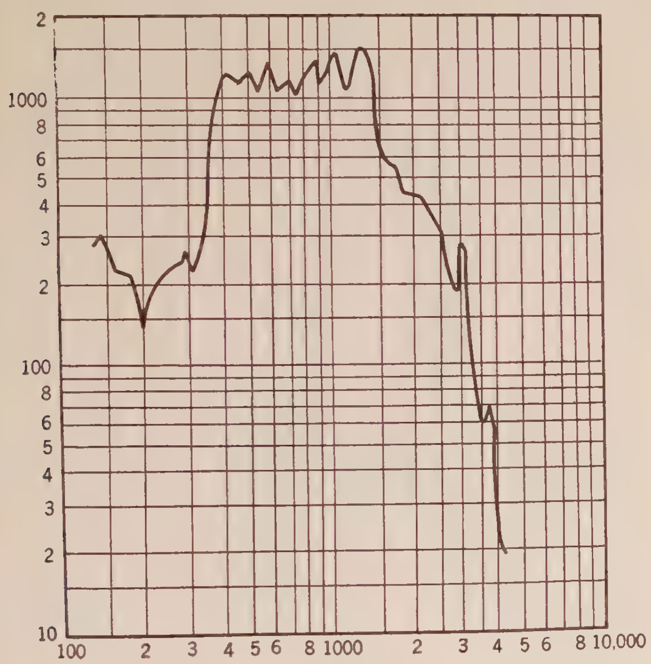



Fig. 6

Fig. 8 shows the pick-up arrangement for measuring the sound from a loud speaker. A condenser transmitter pick-up is considered very close to the ideal sound-receiving instrument and has been used by many investigators as a sound standard. The pick-up of this transmitter is amplified through a resistance amplifier precluding distortion and the resultant current measured on a milliammeter. The last stage containing a step-down transformer, is also used for checking the voltage at each frequency. Hence, any possibility of reduction of received current at low frequencies is balanced by a corresponding reduction of the measured value of voltage.

Sound volume tests were conducted as follows:

The oscillator was operated through the complete range at fairly constant voltage while measurements of sound by condenser transmitter were recorded and corrected by the value of voltage measured at each frequency. This arrangement gives a complete cycle from current to current and is evidently equivalent to the cycle from sound to sound. In addition, a point is obtained at 60 cycles to determine the loudness of very low notes.

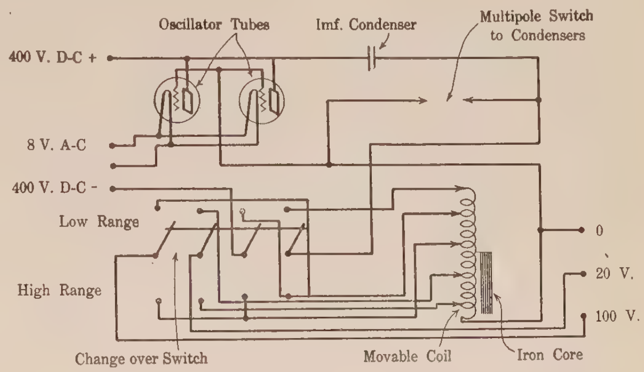



Fig. 7

The above test gives valuable data for investigation of the uniformity of sound and of the absence of resonance points. Listening to the sound, while performing this test, makes it possible to detect any foreign noise, rattle, or sound at a diffferent frequency from that applied.

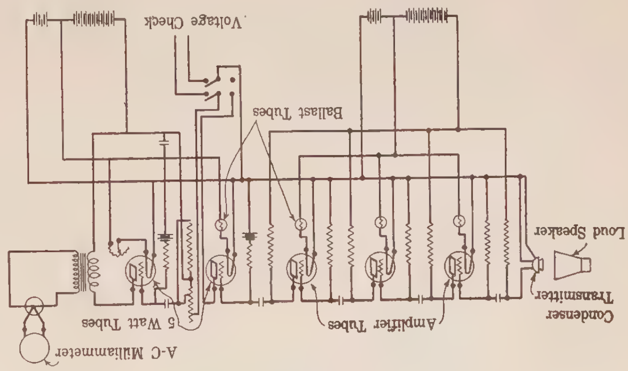



Fig. 8

The ability to reproduce accurately any kind of musical sound or speech can be tested best by actual music and speech reproduction. Again a condenser transmitter has been used for the pick-up of sound. A number of stages of amplification (resistance coupled) bring the current to the loud speaker while an audibility meter is so arranged that the volume can be cut down to any suitable loudness. Each note on the piano repeated several times is one of the best means of detecting any disturbing harmonics. Each note should come

through clear and similar to the original piano note. Low notes, in particular, should be checked for the presence of the fundamental tone. Some designs of loud speakers while giving a loud note at these pitches are found to be completely devoid of the fundamental—the note is just the sum of all overtones.

Speech transmission over the same circuit gives a splendid test for quality and recognizability of reproduction. For proper speech reproduction, the volume should be adjusted to equal approximately the loudness of the original speech. Of course, in a loud speaker designed for a large audience, with a special view to great volume, the speech must sound normal at the volume desired. The same loud speaker would not necessarily give natural reproduction at a lower volume.

An additional test for actual music reproduction is essential. Thus a piano selection, a baritone solo, and a soprano solo are particularly good for detecting

TESTS OF LOUD SPEAKER

| | |
|---|---|
| 1. Measurement of volume 60 to 5000 cycles............ | Uniformity of volume, absence of resonance points and foreign sounds |
| 2. Musical scales on piano..... | Accurate reproduction of quality on each note, particularly the low note. |
| 3. Speech.................. | Clearness of articulation. Individuality of voice. |
| 4. Piano Selection........... | Clearness and naturalness on abrupt tones |
| 5. Baritone and soprano singing | Clearness and naturalness of sustained notes. |
| 6. Flute or violin............ | Reproduction of high notes. |
| 7. Speech and Music......... | Naturalness of superimposed sounds. |

any faults in quality. In addition a violin or a flute solo can be used to advantage to determine the ability of the loud speaker to reproduce the high notes naturally. The table below shows the list of tests and results that can be learned from each.

One more test is very desirable. That is a combination of music and speech. Each possesses individual characteristics and the ideal loud speaker would maintain them. Very often, however, the presence of music will distort the speech and vice versa. Of course, in this latter case we could not expect the loud speaker to reproduce correctly a number of musical instruments simultaneously, although the distorting effect may not be as noticeable as in the case of speech and music.

## Resonating Systems

Considered from a mechanical standpoint a loud speaker is invariably a complicated resonance system. Certain subdivisions of resonance, are, however, possible.

1. *Mechanism as a whole.* In most loud speakers, the diaphragm is the surface producing sound. The force of a magnetic field is in all types except the moving coil type counteracted by a strain in the diaphragm. In a loud speaker of the type shown in Fig. 1, that is, the telephone receiver type, this action is automatic. The diaphragm pulls down until its tension is equal to the pull of magnetic field. In the type shown in Figs. 3, 4 and 5, the normal position of armature is such that the magnetic pull is zero. Actually, however, it is very difficult to keep the armature in this position. Gener-

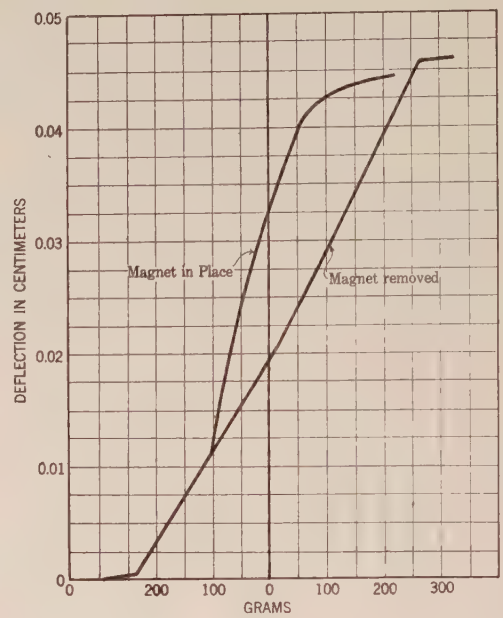



Fig. 9

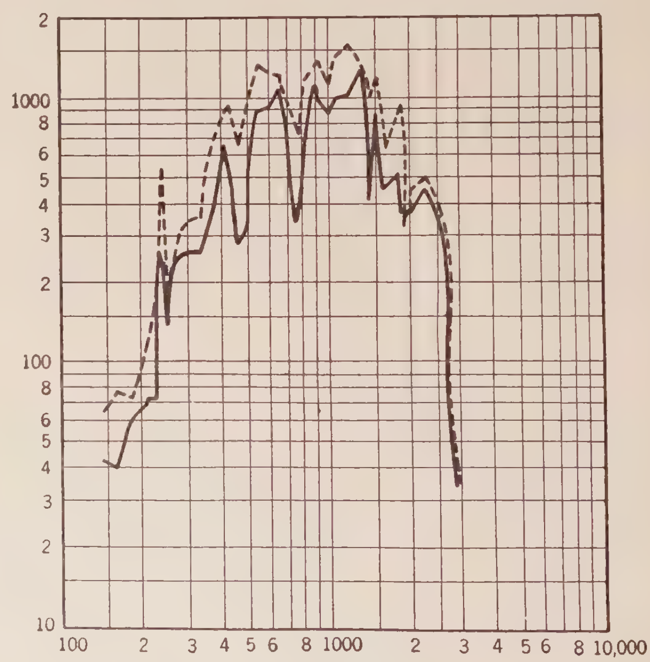



Fig. 10

ally there is a little pull one way or another, balanced by the strain in the diaphragm.

For a movement of the diaphragm, the magnetic field begins to exert a force helping this movement. If the magnetism is increased by using a stronger magnet, the force of the magnet may be made so large that it

pulls the diaphragm over. Normally, a balanced condition may be obtained where very little force is required to produce a certain movement. Fig. 9 illustrates this fact. The two curves show the variation of force on the diaphragm with movement of the diaphragm, and show that with the magnet the diaphragm requires distinctly smaller force for the same movement.

In this way, the strength of the magnet and the tension of the diaphragm determine the force for certain movements and, consequently, the resonant frequency of the whole mechanism. By adjusting the magnetism in a way to get a very close balance, this resonant frequency may be placed very low. As a rule, the damping at these low frequencies is high enough to conceal the resonance; however, the whole of the low

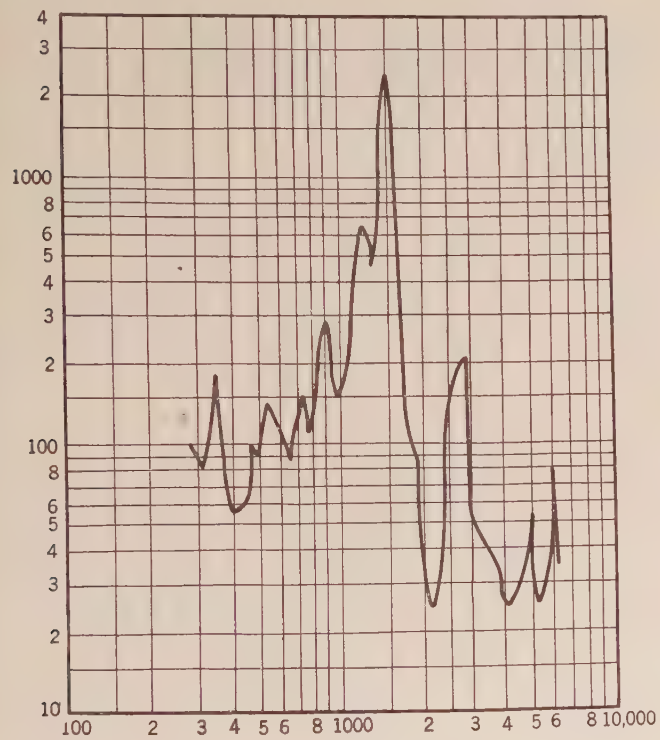



Fig. 11

range will be found raised. This is demonstrated on Fig. 10, showing two curves for one loud speaker, one with a 0.015-in. gap and the other with a 0.010-in. gap. The latter had a close magnetic balance; hence, all notes and the low notes in particular are increased. These curves were taken on relay type loud speaker. It is evident that similar adjustment is possible on all types except the moving coil type; in the latter the resonance point is determined entirely by mechanical strain and the mass of moving parts.

2. *Diaphragm and Horn.* The nature of the diaphragm as a vibrating structure is such that it has a number of resonant notes. Fig. 11, taken on a very stiff small diaphragm, illustrates these resonance points. The lower resonant points can be attributed to the effect of the horn. 1500 cycles is the fundamental of the diaphragm with harmonics at 2900, 5000 and 6000 cycles and higher. The ratios are not exactly 1:2:3:4, but modified by the presence of horn and the nature of the diaphragm.

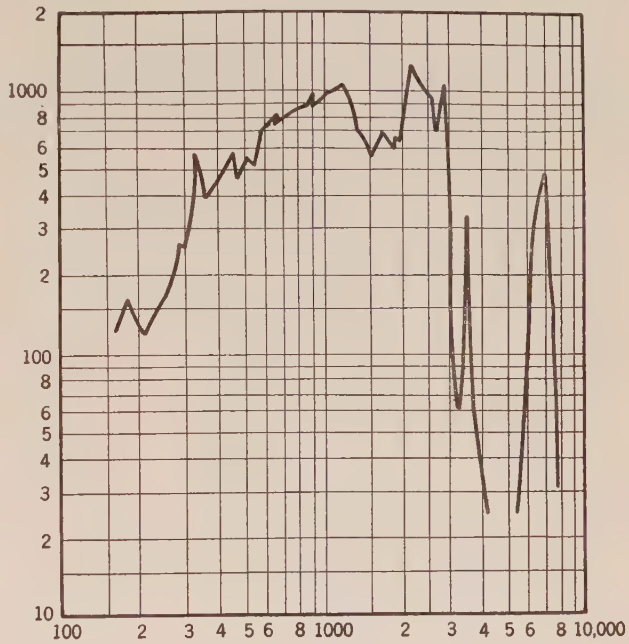



Fig. 12

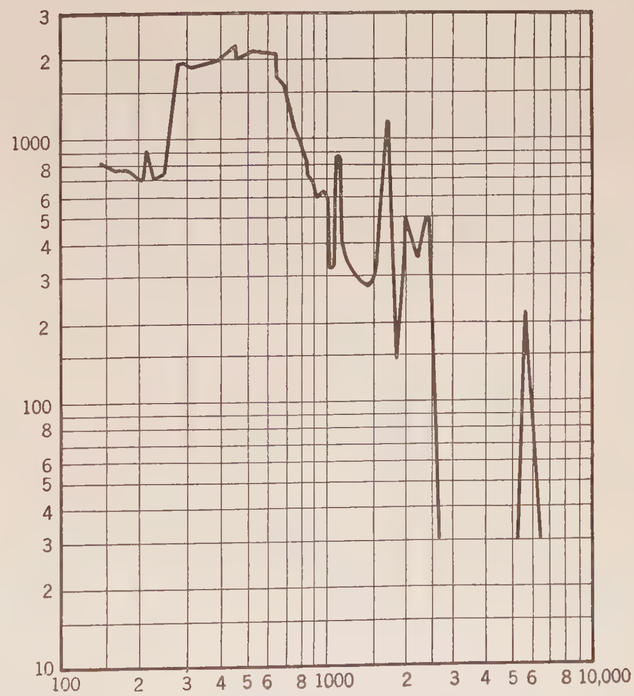



Fig. 13

Fig. 12 shows the resonance in the diaphragm corrugated to reduce the effect of harmonics.

Fig. 13 shows the same kind of curve for a flat diaphragm without corrugation. The resonance points are now more pronounced.

Both these curves were taken without a horn and show the diaphragm resonance only.

The effect of the horn is not independent of the qualities of the diaphragm, because the horn constitutes a load on the diaphragm. If this load is large, it produces a damping effect, which eliminates the resonance of the diaphragm. However, the horn itself has certain resonance points. For example, they can be seen very clearly on a curve like Fig. 10 which was taken on a loud speaker similar to the one used in Fig. 12. If the load due to the horn is small between its resonance points and the resonance of the diaphragm should occur at any of these points, the vibration may be excessive with a resulting rattle and noise. The longer horn favors more uniform load at different frequencies.

The effect of the horn depends to a considerable

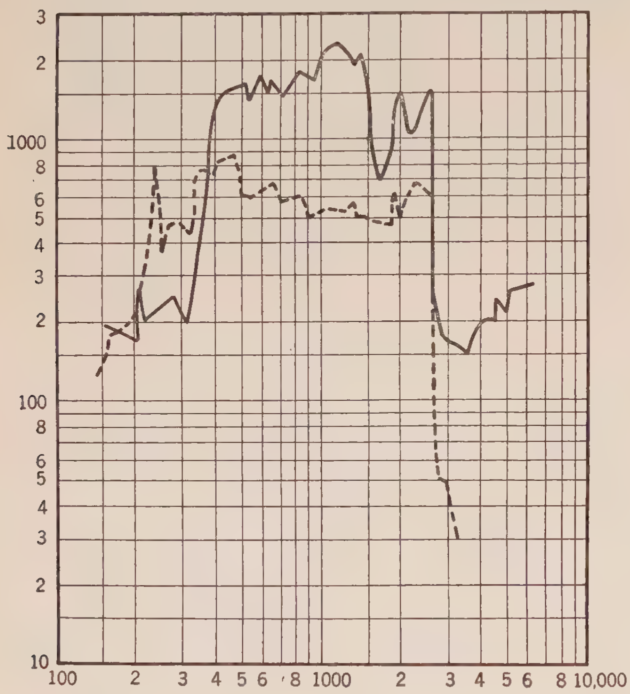



Fig. 14

extent on the power applied to the loud speaker. Fig. 14 shows the intensity of sound per unit voltage from a loud speaker at 20 volts and at 100 volts, each time with a resistance 10,000 ohms in series. At 100 volts the load due to the horn is evidently more uniform than at 20 volts. The intensity per unit voltage is on the average lower at 100 volts.

Speech and music are both modified considerably depending upon the length and shape of the horn, also on the volume of the sound. A horn longer than one quarter wave length of the lowest pitch available gives the best reproduction. However, in practise the length of the horn seldom exceeds three feet, approximately one-fourth of the wave length of 90 cycles, the fundamental of the horn. If the horn is shorter than one foot (270 cycles fundamental the bass and baritone voices are likely to be distorted, since their fundamental, which is below 270 cycles would be reduced. It has been found that a loud speaker with a magnetic balance and a horn about two feet long is capable of very good reproduction of even very low frequencies.

Careful study has been made of materials to be used

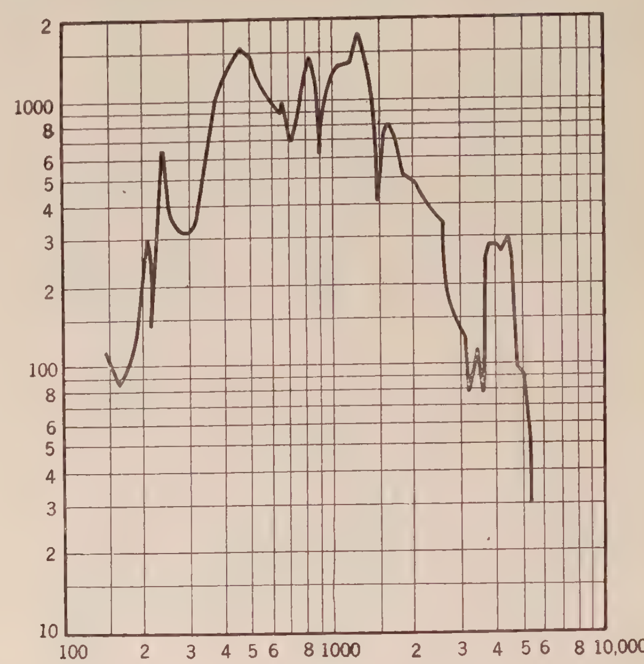



Fig. 15

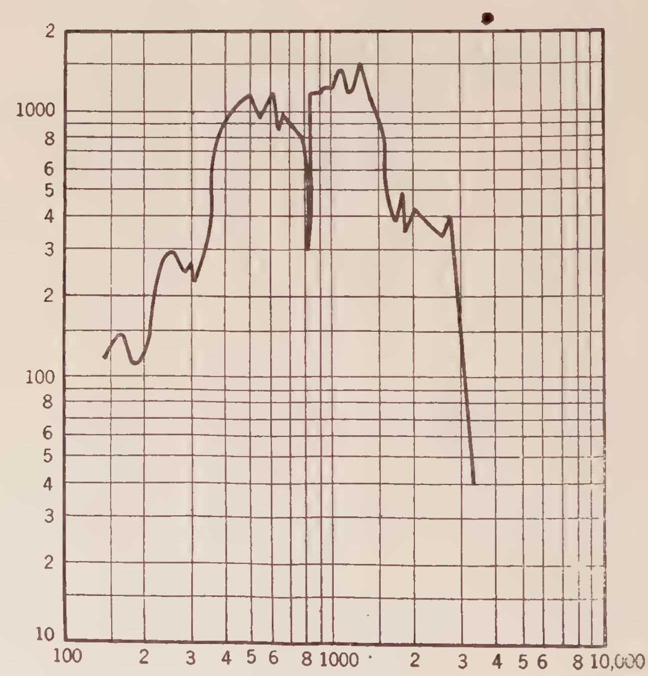



Fig. 16

in diaphragm and in the horn in so far as it affects the quality of reproduction. Aluminum or micarta diaphragms apparently give the best results while a wood horn or horn made of some "dead" material like hard rubber, is least likely to introduce a strange quality.

III. *Armature.* The armature of a loud speaker of enclosed armature or relay type is a strip of steel very short and stiff, but nevertheless possessing a resonance point within the audible range. It has been found that frequencies above this resonance point are difficult to reproduce. Thus, Fig. 15, taken on a loud speaker with a very small stiff armature, shows a range on higher notes extending to 5000 cycles.

Another effect of resonance of armature is the introduction of foreign notes. An example is seen in the Fig. 16 showing a reduction of volume at 800 cycles. At this frequency it was observed that the note had a strange high pitched harmonic; however, damping the armature by a piece of rubber cleared this note and brought up the volume of its fundamental. The trouble was eventually overcome by using a much stiffer armature.

IV. *Strip.* The strip supporting the armature has a resonance note, but the forces acting in it are generally very small compared with the forces in the rest of the system. Hence the effect of the strip is negligible. The only exception is in attaching the strip to supports. It seems that any looseness at this point will result in a rattle.

V. *Connecting rod.* The connecting rod is subject to a complicated torsional and longitudinal strain. Unless this rod is sufficiently stiff, vibrations may be set up which introduce a foreign note at the lower frequencies and limit the sound at the higher frequencies.

### Conclusion

In conclusion a brief summary will cover the outstanding points.

The function of loud speakers is considered as that of a device for converting electric current of frequencies, ranging from 25 cycles to 5000 cycles, into sound waves.

The essentials of this conversion are as follows:

1. Uniform volume at all frequencies.
2. Absence of strange sounds.
3. The ability to reproduce a combination of frequencies correctly.

Four fundamental types of loud speakers are discussed:

1. Receiver type.
2. Moving coil type.
3. Enclosed armature type.
4. Relay type.

Test methods are outlined for:

1. Measuring the volume of sound.
2. Testing the quality of reproduction.

The effect of various parts of a loud speaker on its operation are considered, viz:

1. The magnetic structure.
2. The diaphragm.
3. The horn.
4. The details.

The art of designing a loud speaker is extremely new. The empirical work for ascertaining the effect of various factors is only in its embryo stage.

Eventually, we may expect to design a horn or a vibrating structure with the same facility as an electric motor because a loud speaker is really an electric motor, though its load is less tangible than the load of most motors.

The design of a loud speaker must be based on a scientific analysis of this load and of its reaction on the motor. This involves considerable acoustic research work, mechanical research on vibrating structures and electrical work on the effects of vibrating parts in an electromagnetic structure.

## PLAN TO UTILIZE COLORADO RIVER

The problem of developing the waters of the Colorado River for irrigation and power and to lessen danger from floods in Imperial Valley, is arousing great general interest. The first thing needed in connection with any such development is a survey, but a 300-mile stretch of this 1500 mile river, including the ruggedest part of the Grand Canyon, has not yet been surveyed in any detail. The surveying and mapping of this stretch, which includes the dangerous gorges of the Marble and Grand Canyons, will be started on August 1, as was announced at the Department of the Interior today. This part of the river's course, which is crowded with bad rapids that swirl between steep rock banks, has been traversed on only six previous occasions. It was first explored in 1869, by Major John W. Powell, later Director of the Geological Survey. The present party of engineers and geologists of the Geological Survey will make a trip by boat from Lees Ferry through the canyons to the mouth of the Virgin River, in Arizona, a distance of about 300 miles, and will make records of the slope of this entire stretch of the river and of the topography.

The Colorado, one of the great rivers of the country, is often called the Nile of America. It drains nearly 250,000 square miles, an area equal to that of the Atlantic Coast States from Maine to Georgia. The highest points in its basin are the peaks of the Continental Divide, which stand more than 14,000 feet above sea level, and a part of its water finds its way into Salton Sea, in southern California, which lies more than 250 feet below sea level.

Stretches aggregating about 1200 miles on the Colorado and its principal fork, Green River, and several hundred miles on other tributaries have already been surveyed and mapped by the Geological Survey, and these stretches, together with the 300-mile stretch to be surveyed this year, extend continuously from the town of Green River, Wyo., on Green River, and from Grand Junction, Colo., on Colorado River, to the Mexican boundary.

Detailed examinations are to be made of possible dam sites, which will be considered from both the engineer's and the geologist's point of view. Four boats of special type have been constructed for this work.

# Present Day Practises in Grounding of Transmission Systems

## First Report of Subcommittee on Grounding of Protective Devices Committee A. I. E. E.

THE Subcommittee on Grounding of Systems of the Protective Devices Committee was created on October 14th, 1921, "To Study the special problems and applications of grounding of systems." In order to fulfill its function, the subcommittee prepared an inquiry on the general subject of grounding which was sent out through its members to representative operating companies throughout the United States and Canada.

Thirty-six replies were received to this inquiry covering 6,371,850 kv-a. of generating capacity and 31,408 miles of transmission lines. The data obtained in this manner form the basis of this first report of the subcommittee.

On account of the complexity of the various systems which are not only operated at various voltages but also inter-connected with each other, it has been found necessary to establish some sort of arbitrary classification. Accordingly in the analysis following each transmission section of each company which operated at one voltage has been designated as a system, *i. e.*, each company is said to operate as many transmission systems as it uses different voltages. On this basis the 36 companies reporting operated a total of 111 systems. This definition of a system will be used throughout the report.

With respect to the grounding of neutral problems, transmission systems divide themselves into two main classes, each of which has its own peculiar characteristics radically different from those of the other. The two classes included are:

I—Systems Transmitting at Generated Voltage

II—Systems Transmitting at Higher Than Generated Voltage

In the following report these two classes of systems will be treated in detail separately:

### I—Systems Transmitting at Generated Voltage

BY W. W. WOODRUFF,

Associate, A. I. E. E., Field Engineer, Philadelphia Electric Co.

Twenty companies reported on 31 systems transmitting power at generated voltage, the total generating capacity of which companies was 2,387,500 kv-a. and the total mileage was 8627.

In analyzing the information received, it is intended to point out the features upon which there is general agreement and to indicate those that require further discussion. On account of the complexity of the various systems considerable difficulty has been experienced in getting them on a comparable basis. In order to arrive at some definite means of comparing the different systems, it was endeavored to segregate the actual kv-a. generator capacity of each property, in accordance with the method of grounding employed in the generating station, grouping all capacity of each system, regardless of voltage, in accordance with whether it was dead-grounded, grounded through resistance or ungrounded.

In Fig. 1 the result of this classification is shown very clearly.

It is evident from inspection that by far, the greater portion is grounded through resistance, that the ungrounded system comes next in importance, while the dead grounded system is in the minority. The figures are:

| | |
|---|---|
| Grounded through resistance | 1,901,700 kv-a. |
| Ungrounded | 371,300 kv-a. |
| Dead Grounded | 114,500 kv-a. |

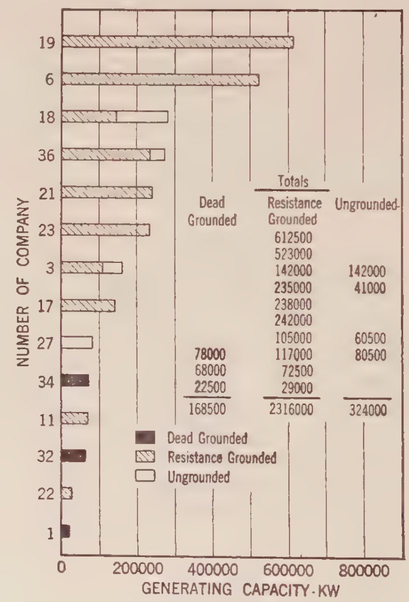



FIG. 1

These figures do not include those systems which transform practically all the power generated to a higher voltage.

This analysis leaves no doubt that the preponderance of opinion is in favor of operating with a neutral grounded through resistance. This generalization must

*Presented at the Spring Convention of the A. I. E. E., Pittsburgh, Pa., April 24-26, 1923.*

be understood to apply only where the generated voltage is used on the distribution system.

The main points brought out by the analysis of the information received are as follows:

a. The tendency is toward operation with some form of grounded neutral.

b. The abolition of the free neutral and adoption of the grounded neutral has decreased cable troubles.

c. The general opinion is in favor of grounding the neutral through a resistance, in preference to the dead-grounded.

d. The relation between voltage and value of neutral resistance as indicated by calculation of the "volts per ohm" shows that a fairly consistent policy has been followed in proportioning the neutral resistance for the various voltages.

e. Where ground relays are used the neutral resistance is generally higher than for systems relaying on phase relays.

f. The cast iron grid resistance box mounted on insulators appears to be giving satisfactory service.

In going over the information submitted, it is interesting to note the changes that have come about with the growth of the properties, and the relative importance of certain engineering features as compared with the amount of generating capacity.

In general, the systems when comparatively young and with small generating capacity were operated without grounds—and the tendency seems to have been to avoid the grounded neutral wherever possible. This policy seems to have been dictated by the desire to prevent accidental grounds from developing into short circuits.

It should be borne in mind that at the time these systems were built, the protective devices for opening breakers and the circuit breakers themselves had not reached their present state of development and that consequently a short circuit was very likely to be accompanied with quite unpleasant results in the stations.

So long as the systems remained comparatively small, and the greater part of the distribution system consisted of aerial feeders, there seems to have been very little reason to complain of the ungrounded system. However, with the increase in the amount of underground work, and consequently the electrostatic capacity of the system, it began to appear that such grounds as did occur had a very disturbing effect, causing surges and high-frequency oscillations that were communicated to otherwise unaffected parts of the system, and furthermore, that the actual location of the circuit in trouble was very difficult.

As the systems continued to increase in size it began to appear that the ground current, or system charging current, had reached such a magnitude that the arc formed at an accidental ground was very destructive and would burn the cable at the fault sufficiently to establish a short before the faulty section could be isolated.

With the advent of this contingency the supposed advantages of the isolated system, in so far as they pertained to the prevention of short circuits disappeared and the tendency in several instances was to go to the other extreme and dead ground the neutral without resistance.

In general, it may be said that dead grounded systems operated quite successfully for a time, but it became evident with the increase of generating capacity that such grounds and short circuits as occurred began to cause disturbances of increasing severity.

While these data do not prove the point, it is known that the first step taken to minimize the effects of the severe short circuits was to place reactors first in the generator leads and then in the outgoing feeders. Eventually, however, the increasing severity of the disturbances caused by grounds led to the insertion of resistance in the neutral connection.

The question naturally arose as to the amount of resistance required and apparently the first tendency was towards the insertion of so great a resistance, that the ground current was decreased to the neighborhood of the normal current of the feeders. Under this condition, it developed that very frequently when a ground occurred, the combined ground and load current was insufficient to operate the overload relays. In consequence, the tendency was again towards decreasing the resistance to a point where the ground current would be sufficient to operate the relays regardless of the extent to which the particular feeder happened to be loaded.

This policy naturally brought the conditions back towards the point where ground currents were of such magnitude that considerable disturbance resulted from them, but the general opinion seemed to be that this condition with the certainty of the ground being automatically isolated, was preferable to the conditions of the less certain operation of the breakers. However, attention naturally turned towards methods of decreasing of the current disturbances, so that at the present time the tendency appears to be towards the increasing of this neutral resistance with the addition of various types of ground detecting, and reverse power relays to automatically isolate any feeder that is defective.

In comparing the replies from the different companies, it is quite interesting to note the relation between the magnitude and nature of the system and the amount of attention which has been given to the matter of grounding. Even with several of the larger companies, where conditions are such that a considerable portion of the construction is aerial, no very careful attention seems to have been given to the system of grounding, or at least to a comprehensive scheme of relay protection, while those companies whose systems are almost entirely underground, and which have a very high standard of operating performance, have gone into the matter in considerable detail.

As to the systems of protections used there seems to be very little standardization of practise except that there may be said that at present the majority of properties rely on the ground current being of sufficient magnitude to trip out the circuit breakers of the affected feeder. This, of course, applied mainly to those systems where there is no provision for ground detecting relays.

However, where ground relays are provided, there is wide divergence in the methods employed, both for the operation of feeder switches, and the making of the ground connections.

Coming to the methods of operating protective relays, a very wide divergence of practise is again noticeable. In some cases, one company may have several different arrangements on various parts of this system.

It does not appear that any of the companies have developed an arrangement which meets with its entire approval as in practically all cases where efforts have been made to develop a system of protection, there are either several different arrangements of apparatus in use, or the arrangement that is in use has not been made universal.

The principal points about which the committees inquiry brought out information are as follows:

### Value of Ground Resistance

The value of the ground resistance must be adjusted in accordance with the voltage, generating capacity, number of points at which the system is grounded, system of relays, size of reactors used, electrostatic capacity of lines, and several other features.

In an effort to determine if there was any relation between the voltage of the system and the neutral resistance, a calculation of the volts per ohm, for each system has been made. That is, the potential from line to ground is divided by the value of the neutral resistance. Consequently, the final values obtained are the "volts per ohm" used in proportioning the resistance. This value—"volts per ohm"—is identical with the "maximum ground fault current" which could exist, assuming that the resistance and reactance of the return circuit, from fault to ground connection was zero, and that the voltage at the fault be held at normal.

VOLTS PER OHM
of
SYSTEMS GROUNDED THROUGH RESISTANCE

| Number of Company | Capacity kv-a. | Voltage | Neutral Resistance | Volts per Ohm | Remarks |
|---|---|---|---|---|---|
| 3 | 105,000 | 13,200 | 4 | 1910* | (*) Indicates values showing very close agreement |
| 6 | 119,500 | 12,000 | 3 | 2310 | |
| | 331,500 | 9000 | 2½ | 2080* | |
| 11 | 46,000 | 11,000 | 5 | 1270* | (*) Indicates ground relays in service |
| 17 | 117,000 | 13,200 | 3 | 2540 | |
| 18 | 241,700 | 13,200 | 2 | 3800 | |
| 21 | 242,250 | 12,000 | 5–10 | 1065* | |
| 22 | 29,000 | 13,200 | 5 | 1765* | |
| 23 | 112,000 | 11,000 | 15 | 423 | |
| 19 | 88,500 | 7800 | 2 | 2250 | Capacity grounded by zig-zag transformers not included |
| | 109,200 | 13,200 | 8.4 | 908* | |
| 36 | 95,000 | 13,200 | 4 | 1910* | |
| | 102,000 | 13,200 | 7 | 1090* | |

In the accompanying tabulation it will be observed that of the thirteen values calculated, eight show a fairly consistent agreement, varying from a minimum value of 908 to a maximum of 2080 and averaging 1500. Of the exceptions, one value, is very much below the average, being 423, and one very much above this average being 3800.

### Number of Points at Which it is Necessary to Ground a System

It appears to be a well established practise to ground at each generating station. The majority of systems find it advisable to ground only one generator on each section of bus. Naturally, the number of points at which it is found necessary to ground will be dependent on the size and extent of the system and to the transformer connections used at substations.

### Arrangement of Switches for Protecting Neutral Resistance and Controlling Ground Current

As to this point there seems to be two schemes of operation diametrically opposed to each other. One of these supplies a switch between the generator and ground, this is sometimes automatic and sometimes hand-controlled, but in either event the operation is to break the ground connection. The other places a short-circuiting switch in parallel with the resistance. Both of these arrangements seems to be designed for the protection of the ground resistance grids, rather than for the protection of the system. In general it appears that the main reliance is placed on the operator locating and clearing the feeder in trouble before the resistance is destroyed. While it is evident that the most desirable practise will depend upon the kind of relay protection in use, there still seems to be considerable room for discussion as to which method is preferable, and the operating phenomena and experience gained in connection with each method.

In Table I is found a tabulation of data covering the above points for a number of the most important systems. These data were very generously furnished by the Electrical Apparatus Committee of the National Electric Light Association.

### Forms of Relay Protection

There are several forms of relay protection in use and all seem to give more or less satisfactory service, although, as mentioned before, the fact that there does not appear to be even two duplicate arrangements, indicates that the operating engineers have not reached any unanimity of opinion as to the merits of the different arrangements.

The systems of most importance are as follows:

a. Ground relay operated from a sheath type current transformer on each feeder.

GROUNDING OF GENERATOR NEUTRALS AND FEEDER GROUND RELAY PROTECTIVE SYSTEMS
THE SYSTEMS INCLUDED TRANSMIT THE GREATER PART OF THEIR OUTPUT AT GENERATED VOLTAGE

| No. of company | System voltage and frequency | No. of generators arranged for grounding | No. of generators in each station operated with neutral grounded | Arrangement of neutral ground connection | Rating of neutral resistors | Feeder ground relays | Settings of feeder ground relays | Number of stations involved | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| 6 | 9000 volts, 25 cycles<br>12,000 volts, 60 cycles | All | One for each section of 25-cycle bus and one for each section of 60-cycle bus. | One resistor between common 25 - cycle neutral bus and ground and one between 60 - cycle neutral bus and ground. | 2.5 ohms, 2000 amperes for 30 seconds. | | | 3 | |
| 19 and 20 | 6600 volts, 25 cycles,<br>11,400 volts, 25 cycles | None, bus grounded through zig - zag transformers. | None | One 3 $\phi$ resistor in series with 3 $\phi$ zig-zag transformer connected to each main bus. | 50 ohms, 66-2/3 amperes per phase, 150 ohms, 200 amperes for 3 $\phi$. | I. T. L. G. E. Bellows Type Relays operated from sheath type current transformers. | 140 amperes minimum<br>200 amperes, 1-1/2 seconds. | 1<br>2<br>3 | The feeder ground relays operate a telephone drop which gives a visual indication of the operation of relays. |
| 20 | 13,200 volts, 60 cycles | All | One | One resistor between common neutral bus and ground. | 7.7 ohms 1000 amperes for 30 seconds. | | | 2 | Resistors of 10 minute rating purchased to replace 30 seconds rating. |
| 18 | 13,200 volts, 60 cycles | All | One | One resistor between common neutral bus and ground. | 2 ohms, 3750 amperes for 2 minutes. (See remarks.) | Westinghouse Type CO 0.5 to 1 5 amp. | Tapered ime settings. All set for same value of current. | 1 | Resistor is made at twelve sections and may be connected to give 2356 on 8 ohms. |
| 8 | 13,200 volts, 60 cycles<br>4600 volts, 60 cycles<br>13,200 volts, 60 cycles | Station No. 1 All<br>Station No. 2 One<br>All | Station No. 1<br>Station No. 2<br>One | Solidly grounded<br>One resistor between common neutral bus and ground in each station. | 4 ohms, 200 amperes for 1 minute. | G. E. Type M. G. | 64 amperes, instantaneous | 2<br>3 | Resistor is made on *t w* |
| 36 | 13,200 volts, 25 cycles | All | One | | 7 ohms, 1100 amperes for one minute. | | | 1 | |
| 23 | 11,000 volts, 60 cycles | Station No. 1 None<br>Station No. 2 All | One | One resistance between common neutral bus and ground. (See remarks.) | 15 ohms, 868 amperes for 30 seconds. | West. Type CO 0.5 to 1.5 amperes | 25 per cent of full-load current. | 1 | Delta Star transformer bank at other station neutral grounded through 15 ohm resistance. |
| 37 | 12,000 volts, 25 cycles | All | One | One resistor between common neutral bus and ground. | 5 ohms | | | | |
| 17 | 13,200 volts, 60 cycles<br>13,200 volts, 25 cycles | None | None | Resistance between transformer neutral and ground. | 3 ohms, 2000 amperes, 1 minute. | 3 | | 2 | |
| 21 | 12,000 volts, 25 cycles | | One | One resistance between generator neutral and ground. | 5 to 10 ohms—water. | Installed | 25 per cent of full-load current. | 3 | |
| 3 | 13,000 volts, 60 cycles | 5 generators, 3 bus tie transformer banks. | One | One resistor for each generator and one for three transformer banks connected to common ground bus. | 4 ohms, 600 amperes for one minute with temp. not more than 750 deg. fahr. | None installed | | 1 | |
| 22 | 13,200 volts, 60 cycles | Two | One | Resistance between neutral of each machine and ground. | 5 ohms on one generator 0.5 ohms on one generator. | | | 1 | |
| 1 | 13,200 volts, 25 cycles | All | All have neutrals solidly grounded. | Solidly grounded | | | | | |

b. Ground relay inserted in the common connection of three current transformers.

c. A similar system operated in connection with a differential relay interconnected with a current transformer in the grounded neutral.

In connection with relaying it is worthy of note that the sheath type transformer is not affected by such triple harmonic currents as may be induced in the common connection of current transformers when a heavy load occurs on the feeder, due to slight difference in the transformers and consequently may be adjusted at a lower setting. It would appear that this point should prove of considerable interest and have a very decided bearing on the selection of the most satisfactory type of relay.

### Special Grounding Arrangements

Two special arrangements were reported. One was zig-zag connected transformer in series with a three-phase resistance connected to the bus bars as shown in Fig. 2. In the other arrangement the neutral of the system was obtained from the middle point of the transformer primary winding of a 5000 kv-a. bank of transformers; the secondary winding being connected in closed delta. The middle point of the star was connected to ground through a 15-ohm resistance. No load was handled by this transformer bank its sole function being to provide a system ground. See Fig. 3.

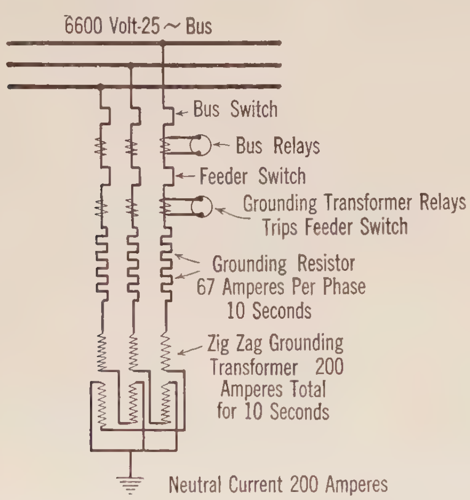



Fig. 2—Bus Grounding Transformers, 6600 Volts, 25 Cycles

### Arc Suppressors

The use of arc suppressors on generated voltage systems does not appear to have any adherents. Apparently, none are, or have been, in service at these voltages. The suppressors have been used at higher voltages but generally have been abandoned even for this service.

### Reactors

The use of reactors is hardly mentioned in any of the replies, however, it is known that many are in use. As these have considerable effect on the short-circuit current, their influence on the operation of the system and of the protective apparatus should be considered.

### Neutral Resistance Construction

The cast iron grid type of resistance mounted on insulators seems to be almost universally adopted, and apparently is giving satisfactory service. The rating of the resistance is usually sufficient to carry the full current to ground for from one-half to two minutes.

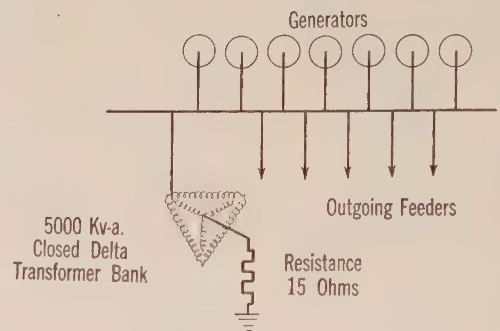



Fig. 3

### Surge Absorbers

One company operating 29 miles of underground cable at 11,000 volts ungrounded reports the use of surge absorbers for protection of the cable. Although these have not been in operation long enough to give conclusive experience they are reported as satisfactory so far.

The above paragraphs have outlined the present general trend of practise on the various points covered, constituting all companies reporting. However, there is a wide divergency of practise and a thorough discussion of each of the points above presented should prove very valuable. In future reports of the subcommittee it is hoped to offer more detailed information relative to the various methods used and results obtained.

All data obtained from the inquiry sent out by the subcommittee are summarized in Tables IA, IIA and IIIA following.

There is also presented in the appendix a series of excerpts from the various reports received which contain much valuable information supplementing the summarized data.

## II—Systems Transmitting at Higher Than Generated Voltage

BY E. C. STONE
Member, A. I. E. E., Chief of Electrical Planning Divisions, Duquesne Light Co.

In this class, thirty-two companies reporting eighty systems with a total generating capacity of 3,984,350 kv-a. responded to the subcommittee's inquiry.

Dead grounding the neutral is clearly the prevailing practise as shown by the following figures:

| | No. of Systems | Total Mileage | Average Miles per System |
|---|---|---|---|
| Ungrounded | 31 | 5377 | 176 |
| Dead Grounded | 39 | 13,037 | 334 |
| Grounded through resistance | 9 | 2626 | 285 |
| Grounded through reactance | 1 | 100 | 100 |

Although the above figures show the trend to be in favor of the dead grounded neutral, the mileage ungrounded is very considerable. The average mileage per system of the ungrounded system is however, less than one half that of the grounded systems. Furthermore a number of the companies reporting ungrounded systems report unsatisfactory operation—generally trouble through high voltage disturbances—and state they are planning to change to grounded neutral operation.

There are several well defined reasons for the prevalence of the dead grounded neutral in this class of systems among which are the following:

a. Higher transmission voltages where a dead ground stabilizes operating conditions and simplifies the insulation problem.

b. Lower maximum currents to ground both on account of the higher reactance in all parts of the system, especially the step-up transformer and of small generating capacities on the average.

c. Greater use of outdoor installations at the higher voltages where line damage is possible from heavy ground currents.

The limitations to the dead grounded neutral is of course the maximum short circuit developed in case of a grounded phase and the damage which may result therefrom.

On systems with dead grounded neutral the usual practise is to ground at fairly frequent intervals; the average number of miles per ground on 34 such systems is 32 as against 136 miles per ground on 9 systems with neutral grounded through resistance.

On long transmissions at high voltage both transmitting and receiving ends are almost invariably grounded, while in high or medium voltage networks the neutrals of the transformer banks are frequently grounded; not only at generating stations but also at all or nearly all step-down systems. This practise is undoubtedly due in part to the simplicity of making dead ground connections. One company reported very frequent grounding on account of soil conditions which makes the conductivity of the individual grounds uncertain.

The only company in this class reporting over one hundred miles of cable reports on three hundred and fifty nine miles at 24,000 volts. The neutrals of the step-up transformers are dead grounded at two generating plants. Automatic switching is prevalent on this system and is operated in a network the same as similar lower voltage systems. Above 30,000 volts, only one company reported operation of cable. This system consists of 28 miles at 33,000 volts constituting two tie lines between principal power plants; each line is supplied with its own step-up and step-down transformers. The high-voltage windings on both being connected in star with neutrals dead grounding. Switching is done on the low-tension side.

Most of the systems in this class operating with resistance in the neutral are of comparatively recent development. The magnitude of resistance used shows wide variation. The prevailing type of resistance is the cast iron grid similar to that used in generating stations, described in the first section of this report.

Two systems, however, are using water rheostats with apparently entirely satisfactory results.

Dominating influences leading to the insertion of resistance in the grounding neutral of high-voltage systems are the rapidly increasing generating capacities of these systems, leading to dangerous currents with dead ground and increasingly rigid demands for high grade service, requiring the elimination of voltage disturbances which would result from heavy ground currents. Conditions making such operation practicable are the high reliability of insulators; development of automatic circuit breakers for heavy duty, at high voltages and improvement in relay systems which make selective relaying possible on ground current of less than full load of the lines protected.

One company reports the use of a Petersen Coil on a 44,000-volt system of one hundred miles extent, all overhead. The installation is a recent one and no comments were made as to the results attained.

Two companies reported former use of the arc suppressor. Both however, regarded this equipment as outgrown and expressed themselves in favor of automatic circuit breakers and selective relays rather than the arc suppressor as protective equipment.

## III—Protection of High-Voltage Underground Cables

While seven companies reported operating 525 miles of cable above 20,000 volts only one of these reported cable operating above 30,000. The subcommittee has, however, also secured data on four British installations of cable which are now in operation at 33,000 volts. The following is a summary of the protective arrangements used on the one American installation and on the four British installations which were reported on:

It will be noted that four out of five systems have neutral dead grounded and operate each cable as a separate unit isolated at both ends by transformers. Only one company attempts anything like a transmission net work with sectionalizing switches.

Inquiry among cable designers which has been made by the subcommittee brings out a definite and uniform opinion that in the present state of the art, cables

| No. of company | Number of lines | Miles each line | Arrangement of neutral | Lightning arresters | Switching: Location | Switching: Method | Scheme of operation |
|---|---|---|---|---|---|---|---|
| 6 | 2 | 14-1/2 | Dead grounded on both lines at both ends | None | Low-tension side | Automatic | Separate step-up and step-down transformers for each cable at both ends |
| 38 | 1 | 15-1/2 | Dead grounded generating end only | None | Same | Same | Same |
| 39 | 2 | 9 | Same | None | Same | Same | All operated through one 33-kv. bus |
| 40 | 2<br>1 | 2-3/4<br>9 | Grounded at step-up transformers through resistance 200 amperes 2 min. | None | High-tension side | Same | |
| 41 | 1 | 4-1/2 | Dead grounded generator end only | None | Low-tension side | Same | Separate step-up and step-down transformers at both ends |

operated at 33,000 volts or above should have the neutral dead grounded at as many points as possible.

With reference to switching practise, the high-voltage, high duty switches now available should prove entirely adequate for switching on both routine and automatic on failure on high-voltage cables. If such cables are to be used to any great extent in future transmission systems the present practise of isolated operation must necessarily give way to operation in net works,—in many cases connected with overhead lines—with the usual automatic sectionalized switches.

Even if greater voltage disturbances are produced by switching at cable voltage rather than on the low-tension side—and opinion is more or less divided on this point—such operation cannot be avoided.

One manufacturer writes as follows with reference to these matters:

"Testing and research have indicated that the low-tension switching generally produces less voltage disturbance than high-tension switching. However, the voltages produced by switching are only a part of the disturbances to which cables are subject. If low-tension switching is used, therefore, there will be a slight probability of fewer troubles in the cable, and where individual transformer banks are used for the cables it is easy to use low-tension switching. There will be many places, however, where it is necessary to use a high-tension bus and high-tension switching. We believe this will be the case in the future and that the system should be made in some way proof against the disturbances resulting from high-tension switching. Future experience will indicate whether this can be done best by increasing the insulation of the cable or by installing protective devices, such as resistance in shunt with reactance or resistance in series with condensers.

While cables are less subject to lightning disturbances than overhead lines, yet, it appears desirable to protect such cables by lightning arresters whether they are connected to overhead lines or not. Since the cost of arresters is low compared to that of the cable, that is, the insurance is cheap, they should without doubt be protected by lightning arresters where they are connected with overhead lines."

## IV—Conclusions and Summary

BY E. C. STONE

Duquesne Light Company, Chairman of Sub-Committee

From general considerations fundamental to the problem and analysis of all data received by the Sub-committee, the following conclusions are reached:

### Operation with Ungrounded Neutral

The only argument in favor of operating a system with ungrounded neutral is the possibility of continuing in operation with one phase grounded. In the early days of power transmission, when mileages were small and voltages low, this was possible not infrequently, and on systems in undeveloped territory, especially with lines running radially out from a central power station, such operation became of distinct economic advantage. However, as the size of these systems increased it was soon found that in a majority of cases that the increased charging currents on a grounding phase not only made continued operation impossible but developed excessive voltages at other points of the system which resulted in one or more break downs, thus causing serious interruptions to considerable portions of the system as well as material damage to valuable equipment.

### When to Ground the Neutral

The grounded neutral of a transmission system performs two definite functions:

a. It acts as an anchor to hold the generator windings, transformer windings and line wires at potentials to ground which are within the values for which a system is designed;

b. It completes, in case of a grounded phase, a closed circuit through the generator which short circuits the electrostatic capacitance, of a system to ground and prevents the building up of arcing grounds involving disasterous voltages.

The dead grounded neutral limits the voltage stresses that may occur at normal frequency to a value of approximately 50 per cent of that which may occur with any other operating arrangement.

The creation of excessive voltages in transmission systems, both from internal surges and arcing grounds depends largely upon the amount of energy storage in the electrostatic capacity of a system which increases

directly as the number of miles of line and as the square of the voltage. Hence the increasing mileage and increasing voltage of transmission systems have been the definite factors leading to grounding of the neutral.

These conclusions have been amply proved by operating experiences. In many cases the excessive voltages have become increasingly frequent and disasterous as ungrounded neutral systems have grown and have subsequently been practically eliminated by the grounding of the system neutral.

From the data available it is not possible to indicate, except in a very general way, at just what stage in the growth of a system the neutral should be grounded. When however, the magnitude of any system has become so great that evidences of excessive voltages become frequent and insulation failures develop simultaneously on different parts of the system, it is time to consider grounding of the neutral.

In this connection, it should be remembered, that because of the higher electrostatic capacity of cables, one mile of cable is equivalent to approximately 25 miles of overhead lines. On all systems reporting only 6385 miles out of a total of 31,408 are operating with free neutral. Mileage of systems is the determining factor in grounding and is shown by the fact that the average mileage per ungrounded system is 152 against a mileage per system with dead grounds of 441 and with resistance grounds of 248. The latter being chiefly on systems consisting largely of underground cable.

## How to Ground

Four factors must be considered when designing a neutral ground for transmission systems:

a. Excessive voltages must be taken care of.

b. Excessive currents must be prevented.

c. Due consideration must be given to conditions imposed by selective relaying.

d. Due consideration must be given to reducing to a minimum the effect of system disturbances on interference with operation of motors and other load.

As previously stated operating experiences show conclusively that dangerous voltage disturbances will become more and more prevalent as *mileage* and *voltage* of systems increase, unless suitable grounding of the neutral is resorted to.

Several companies grounding through a resistance report gradual reduction of resistance as the magnitude of the system increases. With this premise, let it be assumed that for the same degree of protection on various systems, the grounding resistance should vary inversely as the total system charging current. Inductance and electrostatic capacity per mile of overhead line and cable do not vary very widely within the ranges of construction used by the systems under consideration; let them be assumed constant with the electrostatic capacity of cable taken as 25 times that of overhead line. Expressed as a formula these assumptions give the following results:

$$(L\,a + 5 + 25\,L\,b) \times f \times R = K.$$

where:

$L\,a$ = Miles of overhead line
$L\,b$ = Miles of cable
$f$ = Frequency of system in cycles per second
$R$ = Resistance of combined neutral ground circuit, in ohms.

A calculation of the value of $K$ for those systems on which sufficient information is available shows interesting results. If $K$ came out a constant for all systems it would mean that a definite relation had been established between systems charging current and ohmic value of grounding resistance. As a matter of fact however very wide variation is shown as indicated in the following summary:

| | No. of Systems | Value of $K/10^6$ Minimum | Average | Maximum |
|---|---|---|---|---|
| Transmitting at generated voltage.............. | 8 | 0.008 | 1.04 | 3.55 |
| Transmitting at higher than generated voltage. | 7 | 0.022 | 0.52 | 2.00 |

Petersen, inventor of the Petersen grounding coil, has given a value of $K$ of $6.2 \times 10^6$ as suitable for calculating a grounding resistance of proper ohmic value for preventing the accumulative voltage variations from arcing grounds. This would give a value of resistance from 6 to 12 times the average, as shown by the above data, and two or three times the maximum values in actual use.

In view of the fact that some of the later grounded neutral installations have been installed with the highest resistance values it is of interest that one company with a relatively very high grounding resistance reports occasional insulation failures simultaneously at different points on the system, similar to those which previously occurred on the ungrounded system.

So much for the higher limit of resistance value. The lower limit is determined by the maximum permissible current flow in case of a grounded phase and this in turn is determined by the possible damage to equipment and disturbance to service, resulting from such current flow. The limits have however, a considerable range depending on service conditions, system connections, outdoor and indoor bus structures, etc.

The data collected show that of the 49 systems with grounded neutral transmitting at higher than generated voltage and operating 24,926 miles of line 39 systems with 18,478 miles are dead grounded, while only 9 systems with 2626 miles are grounded through resistance.

The reason for the predominance of the dead grounded neutral on the higher voltage systems seems clear when it is remembered that the reactance of a

system goes up at least in proportion to the voltage, with the result that relatively small currents flow in case of a grounded phase at the higher voltages. For example—assume that a 200,000-kv-a. station is designed for 11,000-volt operation and that the generators have 6 per cent internal reactance, the maximum current which could then flow to ground if neutral of all generators were dead grounded would be:

$$\frac{200,000 \times 1.73}{11,000 \times 0.06} = 525,000 \text{ amperes}$$

If however, the generators step up their entire output to 132,000 volts through transformers of 6 per cent reactance and all transformer neutrals are dead grounded, the maximum possible current at the high-tension bus would be reduced to one twenty-fourth of the above value or 20,000 amperes.

From another point of view if it was found that 25,000 kv-a. was the maximum permissible station capacity at 11,000 volts for dead grounded neutral, then a 600,000-kv-a. station at 132,000 volts might have its neutral dead grounded without any increase in maximum possible ground currents. The resistance of a ground circuit through a fault is so low that it is practically negligible compared to the impedance of the rest of the circuit. Hence the greatest currents arising from grounding the neutral may occur at the large stations at the lower voltages and it is at these stations that limitation of ground current by insertion of resistance in the neutral becomes compulsory.

From the point of view of relay operation, the dead grounded neutral is the most satisfactory arrangement, since it allows ample currents for positive selective action of relays and permits using the same relays for protection against grounds and short circuits. A low internal resistance of the order of two or three ohms does not materially alter this condition, since ground currents will be still much in excess of normal full-load line currents. The information received indicates that selective relay requirements, have been a limiting influence in 12 cases on the maximum value of resistance used in neutral grounds. See Tables 6A and 6B.

On the other hand, the demands of a rapidly growing motor load—much of it synchronous—for relief from inconvenient disturbance due to drop of voltage has created a tendency toward the use of greater values of ground resistance particularly on high-voltage overhead systems where most break downs are grounds, rather than short circuits, and individual lines have very large carrying capacities so that a single fault to ground may effect a very large block of service.

In the last few years there has been a fairly marked trend toward the use of higher resistance in grounded neutrals especially in the higher voltage systems. This has led to the development of a number of relay schemes in which selective operation of breakers is obtained with ground currents less than the full-load current of the line. Six companies are using schemes of this nature on parts of their system.

In studying the effects of heavy ground currents on the operation of synchronous machinery a series of tests was made by one of the manufacturers under conditions approximating those of a certain transmission system. The results of this test indicated that the average voltage at the motor could not drop more than 30 per cent without interference with operation. With greater drop in voltage than this motor generators may be expected to drop out of step and rotaries to flash badly. The average drop of thirty per cent at the load, means of course, materially less than this on transmission systems since when the voltage begins to drop, motors immediately draw more current, thus adding to the drop due to ground currents.

Insertion of resistance in the neutral reduces the distortion to the voltage triangle in case of ground, as well as the average drop in voltage.

Calculations of the maximum current which will flow in case of a grounded phase on systems with neutral grounded through resistance have been made by dividing the rated system voltage, from neutral to phase wire, by the resistance, at the grounding point, assumed to be in parallel. On 17 systems for which this information is available the following figures for maximum ground current have been obtained:

| Maximum | Average | Minimum |
|---|---|---|
| 5950 Amperes | 2080 Amperes | 102 Amperes |

Under 700 amperes, 5 systems: 1100 to 2600 amperes, 8 systems: 4000 amperes or over, 4 systems.

### Type of Resistance

Details of the data obtained by the Subcommittee will be found in Tables 3A, 3B, 6A and 6B. Prevailing practise calls for grounding resistances made up of cast iron grids for either indoor or outdoor operation.

These grids are designed for a maximum temperature of 350 deg. cent. to 600 deg. cent. The average being about 400 deg. cent. On 30 grids now in service, the time required to reach this temperature runs from 10 seconds to two minutes with an average of 45 seconds. One grid has a time rating of 10 minutes having replaced a 30-second grid on account of burning out of the latter.

In general, these grids are giving satisfactory service. Of 11 systems for which information was furnished on this point, 8 reported no trouble, while 3 using thirty second resistances and one having a 10 second resistance reported trouble from burnouts on sustained grounds. Of two of these using 30 second grids, one has gone to dead grounding and the other to 10 minute rating, while the company using the 10 second resistance on a 66-kv. system has installed a circuit breaker to automatically short-circuit the grids on maximum ground current sustained for 10 seconds.

Two companies are using water rheostats for ground-

ing resistance, the ohmic values are five to one hundred and fifty ohms. One of these reported satisfactory operation and one burnout due to low capacity. One company reports resistance of 60 to 100 ohms made of

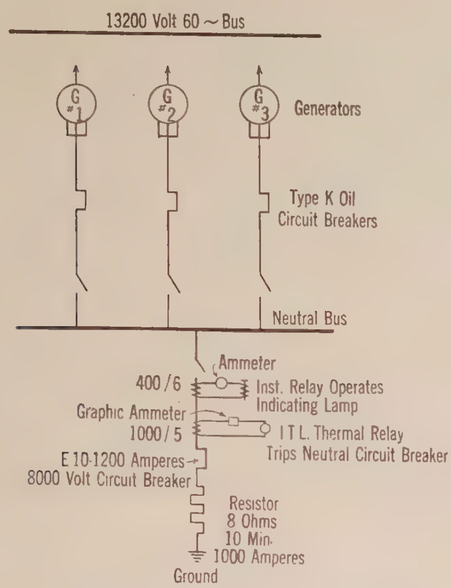



Fig. 4—Grounding of 13,200-Volt, 60-Cycle System

Monel metal, the ratings being 67 amperes for 10 seconds and 40 amperes for 20 seconds respectively.

## Grounding Through Reactance

The most recent development in methods of grounding of neutrals is the use of a reactance instead of

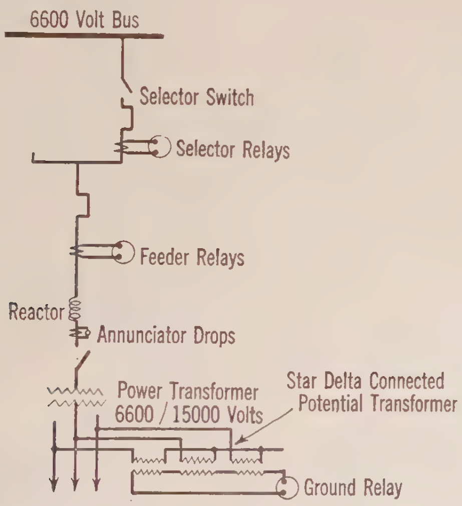



Fig. 5—Showing Method of Grounding and Protecting 15,000-Volt, 25-Cycle Station Tie

resistance. If for any given system, the reactance is properly proportioned it will exactly neutralize the capacitance of the transmission system to ground, so that in case of a grounded phase no current will flow through the fault. It is claimed that arcing grounds are absolutely prevented by this device which is called the Petersen coil, after its inventor.

Although a number of his schemes of grounding through reactance have been in operation for some time in Europe, only one company in the United States was reported to the subcommittee to be using it. A thorough analysis of the theory of the grounding reactance was presented by Messrs. Conwell and Evans in the A. I. E. E. Journal for February, 1922, and a report on practical results obtained from operation of such a coil over a period of eighteen months is presented by Messrs. Oliver and Eberhardt coincidently with this report.

Grounding the neutral of a transmission system in a suitable manner is thoroughly standardized in the United States as the best protective measure against internal voltage disturbances. This conclusion is definitely proved by the data received by the subcommittee.

## Protective Schemes Other Than Grounded Neutral

Several companies have used various forms of arc suppressors with more or less success, for a number of years. Outlines of their experiences will be found in the "excerpts" in the appendix of this report.

In general the arc suppressor has proved only reasonably successful as it has many limitations. The concensus of opinion seems to be that with the high duty circuit breakers and selective relaying now available the arc suppressor should be abandoned. One company reports the use of surge absorbers on their ungrounded cable systems with satisfactory results. This device consists of reactance and capacitance in series in the form of a static condenser and this connected into the line in a manner similar to lightning arresters. The use of this device is suggested in addition to the dead grounded neutral for protection of very high-voltage cables.

In Europe it appears that considerable success in protecting against excessive voltages has been obtained by the use of horn gaps in series with the resistance connected to the line, the same as lightning arresters.

One case has come to the attention of the subcommittee where the neutral of a transformer bank was connected through a spark gap to ground.

In conclusion the present situation as to grounding the neutral of transmission systems is summarized in the following paragraphs:

1. Grounding the neutral has proved successful to a very high degree in limiting trouble from excessive voltage on transmission systems. Case after case is on record where frequent and destructive insulation break downs on systems operating ungrounded have been practically eliminated after the neutral is grounded.

2. The trend of present practise is definitely toward grounding the neutral of large transmission systems.

Increasing mileage and voltage have been the factors necessitating this practise:

a. On systems transmitting at generated voltage, the neutral usually is grounded at each generating station with resistance of low value.

b. On systems transmitting at higher than generated voltage the neutrals of the transformers are grounded at each generating station and some or all substations.

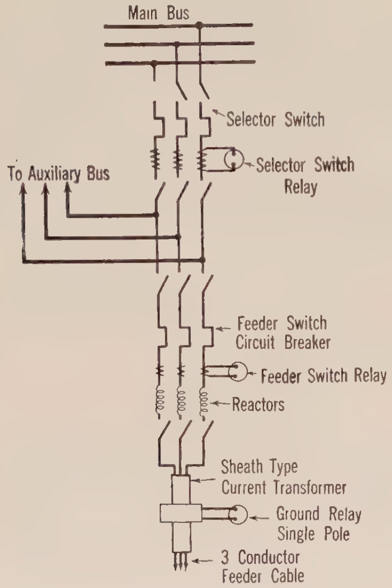



Fig. 6—6600 and 11,000-Volt Radial Feeder Relays, 25 Cycles

c. Where resistances are used they are generally made up of cast iron grids with time ratings at maximum current of 30 seconds to 60 seconds.

3. The use of arc suppressors has been very generally abandoned. This is not because such apparatus was without merit since some fairly good results were obtained with its use, but rather because of the development of high interrupting capacity breakers and selective relays which are found to be a better solution to the problem.

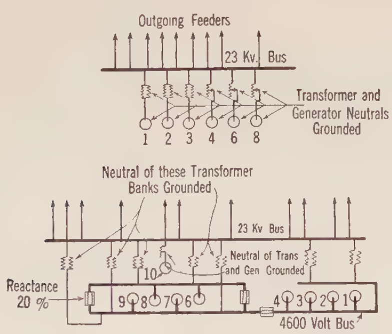



Fig. 7

These two plants are operated in parallel.

4. Certain departures from present standard practise in neutral grounding as outlined above are taking place which are apparently proving successful and are likely to become increasingly used:

a. High resistances in the neutral ground connection of the order of one to one and one half ohms per thousand line volts. One company is using a resistance of 150 ohms on a 26,400-volt system.

b. Reactance, (Petersen coil), is being tried instead of resistance in the neutral ground connection.

## Excerpts from Replies to Inquiry

The following excerpts, which are taken from the replies submitted in answer to the questionnaire, give in a general way the attitude of the various operating engineers towards this subject. These replies refer to the systems as a whole and include lines operated both at generated and transformed voltages, and, consequently, refer to methods of grounding the neutrals on the high-tension side of transformer banks as well as the generator neutrals.

The company number at beginning of each excerpt furnishes a reference to other data on same company in the tables.

### Company No. 1

(1-A). The method of grounding is considered entirely satisfactory. The only difficulty which has been experienced is the burning up of the cast iron rheostat in case the ground, due to failure of some other protective equipment, should hang on too long.

When the main power house started in operation the neutral of one of the transformers connected to each of the two high-tension circuits was connected directly to ground without any resistance. As the summer of 1911 proved that these lines were subject to considerable lightning trouble it was tried for a while to run the system ungrounded, but as this did not minimize the effects from lightning this method of operation was quickly abandoned again in favor of the grounded system which permitted selective relay operation by means of neutral relays in the ground connections. Resistances between the neutral points of the transformers and the ground were shortly after introduced because it was believed that some of the transformer breakdowns experienced during 1911 might have been due to excessive flow of current which would occur through the dead grounded transformer when only one of a number of transformers in parallel was grounded. Resistances made of concrete separating electrodes of wire netting were first tried but proved entirely unsuitable as they would cause arcing when heavy current passed through them and were abandoned in favor of the present cast iron grid rheostats.

Arc suppressors and a field destroying device have been used a number of years on the transmission system with fair success. Both have been abandoned, however, due to the fact that they were found unnecessary, as four parallel circuits have been constructed and an elaborate relay system of overload and neutral relays at the generating station and reverse power relays

at the terminal station have been brought to such perfection that the other devices were found unnecessary on the system.

(1-B). We originally operated without neutral grounded. About 1907 we grounded the neutral of one generator through a grid resistance having 10 ohms. The object of this grounding was to reduce voltage strains on the system. As the capacity of our system increased it became necessary to reduce the resistance of the grounding resistance to accomplish the same results. About 1915 we burned up the grounding resistance and as we were approaching zero resistance we decided to abandon the resistance. Since that time we have operated with the neutral solidly grounded and have found this practise satisfactory.

### Company 5

We originally installed resistance in series with the neutral but it was abandoned, and since we have been operating with a dead-ground we had an arc suppressor a number of years ago, but it did not seem to be of any particular service.

### Company 7

The operating condition during the period from February to August was such, however, that for all practical electrical considerations the system was operated as a purely grounded system. On ungrounded operation, from the beginning of March to the end of August 1920, 61 cases of trouble interfered with the operation of the system. Upon investigation it was found that there were actually 120 cases of trouble; that is, usually each case of trouble brought with it a reflected case of trouble; *i. e.* interference with operation was usually caused by more than one sumultaneous breakdown. We have record of five cases of breakdown occurring simultaneously and as can be readily imagined it was somewhat difficult, if not impossible to actually establish which was the primary cause. Against the before-mentioned our operating experience for the same period in 1921 with dead grounded neutral showed that there were 47 cases of operating interference and but 48 cases of trouble found. This means that when a breakdown occurred on the grounded star-connected system it stayed as an individual case and did not bring with it a multiplicity of simultaneous breakdowns.

### Company 9

Full load on our feeders is from 200 to 250 amperes. The relays are adjusted to trip on approximately 120 amperes ground current.

### Company 11

Before grounding neutral, simultaneous cable failures did occur and in one case five faults appeared. Since grounding neutral only one has occurred when two feeders failed at once.

### Company 18

The 150-ohm resistances in the two 26,400-volt sections have not been in service long enough to supply sufficient data regarding the suitability of this value of resistance. The ungrounded sections in are not entirely satisfactory in comparison with grounded operation.

### Company 20

On four occasions the 1000-ampere, 30-second resistor through which the neutral bus of the 60-cycle, 13,200-volt system was grounded failed in service because of sustained grounds on other station busses with the ground current divided over several feeders. In each case the resistor burned apart leaving the neutral bus ungrounded.

A new resistor rated at 8 ohms, 100 amperes for 10 minutes has been installed. A thermal relay with current time characteristics similar to those of the resistor opens an oil circuit breaker in series with the resistor when the grids reach a dangerous temperature.

### Company 21

Our system was first changed from free neutral to solid grounded neutral. This eliminated the trouble due to surges but caused our lead cable sheaths to be burned when the line became grounded. To remedy this, we changed from solid grounded neutral to neutral grounded through resistance. After trying various values of resistance, we have found that approximately 5 to 10 ohms gives very satisfactory results on our systems.

### Company 24

No trouble has been experienced with the resistance used in grounding the neutral of our transmission system, while in service. Inspection of the grids has shown broken grids at various times. However, as the units are built up with two grids in parallel, this at no time has opened up the circuit to ground.

### Company 29

As our 11-kv. system has increased in extent and consequently in electrostatic capacity, surges due to arcing grounds have become increasingly violent. They are particularly destructive to lightning arresters, cable terminals, transformers etc., we therefore propose when one new 15,000-kw. 11-kv. turbo generator is installed to ground the neutral of the system, but whether through resistance or not has not yet been determined.

### Company 36

The 60-cycle system was originally operated with a free neutral but after failure of the insulation of a large generator, cause of which was attributed to voltage disturbances which would very likely not have occurred had there been a neutral ground connection, plans were made for connecting this neutral to ground through an 8-ohm resistor.

Experience obtained during the next few years indicated that there was a certain number of faults to ground through which the current was not of sufficient value to cause the circuit breakers to open, and it, therefore, appeared advisable to reduce the resistance with the ground connection. This was done in such a manner as to obtain a resistor of 4-ohm resistance designed to carry 2000 amperes for one minute.

At the present time there is a number of trial installations of low-current ground relays connected in the common return wire of the current transformer secondaries which operate alarms to indicate to the operator which line is grounded. Owing to the fact that nearly all transmission is through underground cables, the ground faults usually develop into short circuits before the operator can clear the line manually. It is possible that in the future installations will be made of ground relay protective equipments which will automatically insolate a grounded section.

### Company 10

At the time the plant was built, the manufacturers did not feel capable of building 110,000-volt oil switches which could be relied on to open short circuits safely with the power of the plant behind them. Instead, therefore, of relieving short circuits which might occur on the 110,000-volt lines by automatically opening the supply with oil switches, all of these oil switches were made non-automatic and provision made for lowering the voltage on the line in trouble by cutting in resistance of the exciter fields. After the arc was extinguished in this manner the voltage was again brought up on the units and service re-established.

You will see that the above method of operation meant that every time a short circuit occurred on the circuits service was interrupted. We therefore looked around for some suitable way of taking care of such service interruptions and installed the arc suppressor for that purpose.

The arc suppressor has very satisfactorily performed the work for which it was intended and has taken care of about 80 per cent of the line flashovers, which are practically all caused by lightning, without the loss of load. On the other hand, severe short circuits at receiving end caused by cable failures, etc., also operate the arc suppressor and under such conditions the load is generally shaken off, so you will see that there are times when we would be better off without the arc suppressor.

In addition to the above, there is no doubt in my mind but what the short circuits which the arc suppressor places across the lines at the power house is very severe on the transformers and while we have had no failures of such apparatus, it has never seemed to me just right to place such severe short circuits on the generating equipment if it could be avoided.

The state of the art at present is such that I believe if we were building a new plant at the present time, all of the outgoing lines would be equipped with suitable oil switches which would be made automatic and short circuits would be taken care of by promptly opening the circuit in trouble. For this reason I believe our arc suppressor equipment is out of date and I doubt very much whether a story of the operation of the arc suppressor would be of very much value, except as a matter of history.

SUMMARY OF DATA

| | Systems at generated voltage | Systems at higher than generated voltage | All systems |
|---|---|---|---|
| Number of Companies | 20 | 32 | 36* |
| Number of Systems: | | | |
| Ungrounded | 11 | 31 | 42 |
| Dead Grounded | 3 | 39 | 42 |
| Resistance Ground | 17 | 9 | 26 |
| Reactance Ground | 0 | 1 | 1 |
| Total | 31 | 80 | 111 |
| Total Mileage: | | | |
| Ungrounded | 1008 | 5377 | 6385 |
| Dead Grounded | 3797 | 14,678 | 18,475 |
| Resistance Ground | 3822 | 2626 | 6448 |
| Reactance Ground | 0 | 100 | 100 |
| Total | 8627 | 22,781 | 31,408 |
| Average Mileage: | | | |
| Ungrounded | 92 | 176 | 152 |
| Dead Grounded | 1270 | 377 | 441 |
| Resistance Ground | 225 | 292 | 248 |
| Reactance Ground | | 100 | 100 |
| Resistance Factor $K$: | | | |
| Minimum | 0.008 | 0.022 | 0.008 |
| Average | 1.04 | 0.52 | 0.80 |
| Maximum | 3.55 | 2.00 | 3.55 |
| Maximum Ground Current: | | | |
| Minimum | 425 | 102 | 102 |
| Average | 2300 | 2000 | 2080 |
| Maximum | 4620 | 5950 | 5950 |
| Miles per Ground: | | | |
| Dead Ground | 24 | 32 | .. |
| Resistance Ground | 110 | 146 | .. |
| Reactance Ground | .. | 100 | .. |
| Total Generating Capacity | 2,387,500 | 3,984,350 | 6,371,850 |

*Some companies operate both types of system.

TABLE I-A—TRANSMISSION AT GENERATED VOLTAGES UNGROUNDED SYSTEMS

| Voltage | No. of Company | Miles | | | Protection Other Than Ground |
|---|---|---|---|---|---|
| | | Over-head | Under-ground | Total | |
| 11,000 | 13 | 69 | 7 | 76 | |
| | 18 | .. | .. | 63 | Arc suppressor |
| | 27 | 26 | 29 | 55 | High-frequency absorber |
| | 29 | 315 | 0 | 315 | |
| 13,000 | 5 | 133 | .. | 133 | |
| 13,200 | 18 | .. | .. | 115 | Arc suppressor |
| | 25 | 5 | 0 | 5 | |
| | 26 | 70 | 6 | 76 | |
| | 31 | 0 | 50 | 50 | |
| | 34 | 92 | 0 | 92 | |
| | 35 | 28 | 0 | 28 | |

TABLE I-B—TRANSMISSION AT HIGHER THAN GENERATED VOLTAGES
UNGROUNDED SYSTEMS

| Voltage | No. of company | Miles Overhead | Miles Underground | Miles Total | Voltage | No. of company | Miles Overhead | Miles Underground | Miles Total |
|---|---|---|---|---|---|---|---|---|---|
| 15,000 | 15 | 28 | 0 | 28 | | 25 | 23 | 0 | 23 |
| | 26 | 45 | 0 | 45 | | 26 | 185 | 0 | 185 |
| 17,500 | 12 | 88 | 0 | 88 | | 27 | 90 | 0 | 90 |
| 19,000 | 34 | 68 | 0 | 68 | | 33 | 115 | 0 | 115 |
| 20,000 | 7 | 80 | . | 80 | 44,000 | 2 | 80 | 0 | 80 |
| 22,000 | 2 | 60 | . | 60 | | 12 | 305 | 0 | 305 |
| | 11 | 22 | 0 | 22 | | 34 | 89 | 0 | 89 |
| | 12 | 122 | 0 | 122 | 50,000 | 4 | 895 | 0 | 895 |
| | 27 | 94 | 0 | 94 | 66,000 | 3 | 21 | 0 | 21 |
| | 30 | 217 | 0 | 217 | | 4 | 355 | 0 | 355 |
| | 31 | 580 | 0 | 580 | | 13 | 29 | 0 | 29 |
| 24,000 | 21 | 135 | 0 | 135 | | 33 | 467 | 0 | 467 |
| | 33 | 70 | 0 | 70 | | 36 | 31 | 0 | 31 |
| 26,400 | 31 | 240 | 0 | 240 | 75,000 | 12 | 171 | 0 | 171 |
| 33,000 | 7 | 93 | 0 | 93 | 140,000 | 12 | 518 | 0 | 518 |
| | 13 | 61 | 0 | 61 | | | | | |

TABLE NO. II-A—SYSTEMS DEAD GROUNDED
TRANSMISSION AT GENERATED VOLTAGE

| Voltage | No. of Company | Frequency | Miles Overhead | Miles Underground | Miles Total | No. of Grounds | Location of Grounds |
|---|---|---|---|---|---|---|---|
| 11,000 | 10 | 60 | 3596 | 0 | 3596 | ? | At all company substations |
| 13,200 | 1 | 25 | 5 | 75 | 80 | 3 | Neutrals of generators and transformer banks |
| 13,200 | 32 | 25 | 89 | 32 | 121 | 1 | Generator neutral grounded on condenser piping |

TABLE NO IIB—SYSTEMS DEAD GROUNDED
TRANSMISSION AT VOLTAGES HIGHER THAN GENERATOR VOLTAGES

| Voltage | No. of Company | Frequency | Miles Overhead | Miles Underground | Miles Total | No. of Grounds | Neutral of transformers grounded at |
|---|---|---|---|---|---|---|---|
| 15,000 | 16 | 50 | 385 | 4 | 389 | 5 | Generating and substations |
| 16,500 | 20 | 25 | 0 | 13 | 13 | 1 | |
| 17,000 | 30 | 60 | .. | .. | 327 | ? | |
| 20,000 | 6 | 25 | 13 | 80 | 93 | 4 | Step-up substations |
| 22,000 | 6 | 60 | 10 | 17 | 27 | 4 | Step-up substations |
| 24,000 | 8 | 60 | 578 | 359 | 937 | 2 | Generating stations |
| 25,000 | 3 | 60 | 7 | 14 | 21 | 3 | Step-up substations |
| 26,400 | 1 | 25 | 30 | 10 | 40 | 2 | Step-up substations (auto transformers) |
| 30,000 | 10 | 60 | 105 | 0 | 105 | 3 | Step-down substations |
| 30,000 | 16 | 50 | 69 | 0 | 69 | 4 | Generating and substations |
| 30,000 | 16 | 60 | 110 | 0 | 110 | 7 | Generating and substations |
| 33,000 | 6 | 60 | 0 | 28 | 28 | 4 | Step-up substations |
| 33,000 | 7 | 60 | 657 | 0 | 657 | 4 | Substations |
| 33,000 | 14 | 50 | .. | .. | 105 | 5 | Substations |
| 44,000 | 2 | 60 | 240 | 0 | 240 | 2 | Substations |
| 44,000 | 5 | 60 | 709 | 0 | 709 | 1 | Substations |
| 48,000 | 8 | 60 | 212 | 0 | 212 | ? | Step-up substations |
| 50,000 | 16 | 50 | 204 | 0 | 204 | ? | Generating and substations |
| 55,000 | 28 | 60 | 344 | 0 | 344 | ? | Generating and substations |
| 60,000 | 16 | 50 | 901 | 0 | 901 | 21 | Generating and substations |
| 60,000 | 16 | 60 | 99 | 0 | 99 | 2 | Generating and substations |
| 60,000 | 30 | 60 | 2042 | 0 | 2042 | 129 | Generating and substations |
| 66,000 | 10 | 60 | 910 | 0 | 910 | 43 | All generating and substations |
| 66,000 | 24 | 60 | 26 | 0 | 26 | 1 | Generating station only |
| 66,000 | 29 | 60 | 72 | 0 | 72 | 2 | |
| 66,000 | 33 | 60 | 180 | 0 | 180 | 1 | Generating station only |
| 66,000 | 34 | 60 | 460 | 0 | 460 | ? | |
| 87,000 | 28 | 60 | 224 | 0 | 224 | 1 | All points |
| 100,000 | 4 | 60 | 11,000 | 0 | 1100 | 3 | |
| 100,000 | 5 | 60 | 1489 | 0 | 1489 | 8 | |
| 100,000 | 28 | 60 | 298 | 0 | 298 | ? | All points |
| 110,000 | 2 | 60 | 564 | 0 | 564 | 3 | |
| 110,000 | 10 | 60 | 193 | 0 | 193 | 6 | Generating and substations |
| 110,000 | 13 | 25 | 144 | 0 | 144 | 1 | Generating stations |
| 110,000 | 14 | 50 | 90 | 0 | 90 | 1 | Generating stations |
| 110,000 | 30 | 60 | 515 | 0 | 515 | 12 | Generating stations and substations |
| 110,000 | 31 | 60 | 75 | 0 | 75 | 1 | Generating stations |
| 132,000 | 33 | 60 | 186 | 0 | 186 | 2 | Generating stations |
| 150,000 | 16 | 50 | 480 | 0 | 480 | 3 | Generating stations |

TABLE III-A—SYSTEMS GROUNDED THROUGH RESISTANCE
TRANSMISSION AT GENERATED VOLTAGES

| Voltage | No. of Company | Frequency | Miles Overhead | Miles Underground | Miles Total | No. of Grounds | Resistance Per Ground | Resistance Type | Resistance Rating Amps | Resistance Rating Time-Sec. | Resistance Temp. | Location of Ground Connection |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6000 | 36 | 25 | .. | .. | 10 | 2 | 7 | Grid | .. | .. | .. | Generator neutral |
| 6600 | 19 | 25 | 0 | 416 | 416 | 3 | 1-100 | Grid | 40 | 20 | .. | Generator neutral |
| | | | | | | | 1-60 | Monel-metal | 67 | 10 | .. | Generator neutral |
| | | | | | | | 1-? | .. | .. | .. | .. | Generator neutral |
| 7800 | 19 | 60 | 0 | 151 | 151 | 1 | 2 | Grid | 2300 | 30 | .. | Generator neutral |
| 9000 | 6 | 60 | 0 | 396 | 396 | ? | 2-½ | Grid | 2000 | .. | .. | Generator neutral |
| 11,000 | 11 | 60 | 46 | 31 | 77 | 1 | 4 | Grid | 1500 | 60 | 350° C | Generator neutral |
| | 19 | 25 | 0 | 108 | 108 | 2 | 40 | Grid | 150 | 60 | .. | Transformer neutral at power stations |
| | 23 | 60 | 160 | 151 | 311 | 1 | 15 | Grid | 868 | 30 | .. | Transformer neutral at power stations |
| 12,000 | 6 | 60 | 22 | 353 | 375 | 4 | 3 | Grid | 2000 | .. | .. | Generator |
| | 21 | 25 | 27 | 143 | 170 | ? | 5 to 10 | Water | .. | .. | .. | One generator in each group |
| 13,200 | 17 | 25 | 65 | 33 | 98 | 1 | ? | Grid | 2000 | 60 | .. | Generator neutral |
| | 17 | 60 | 146 | 85 | 231 | 1 | 3 | Grid | 2000 | 60 | .. | Generator neutral |
| | 18 | 60 | .. | .. | ? | 1 | 2 | Grid | 3750 | 120 | 450° C | Generator neutral |
| | 19 & 20 | 60 | 0 | 166 | 166 | 2 | 8 | Grid | 1000 | 30 | .. | One generator in each power station |
| | | | | | | | | | 1000 | 600 | .. | |
| | 22 | 60 | 25 | 0 | 25 | 1 | 5 | Grid | 1600 | 60 | 400° C | Generator neutral |
| | 36 | 25 | .. | .. | 33 | 1 | 7 | Grid | .. | .. | .. | Generator neutral |
| | 36 | 60 | .. | .. | 170 | 1 | 4 | Grid | .. | .. | .. | Generator neutral |
| 13,800 | 3 | 60 | 71 | 353 | 424 | 2 | 4 | Grid | 2000 | .. | .. | Neutral of one generator and one transformer |

TABLE III-B—TRANSMISSION AT HIGHER THAN GENERATED VOLTAGE
SYSTEMS GROUNDED THROUGH RESISTANCE

| Voltage | No. of Company | Frequency | Miles Overhead | Miles Under ground | Miles Total | No. of Grounds | Resistance Per Ground | Resistance Type | Resistance Rating Amps | Resistance Rating Time Secs | Resistance Temp. | Neutral of transformer grounded at |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22,000 | 23 | 60 | 172 | 0 | 172 | 7 | 15 | Grid | 868 | 30 | .. | Feeding substations |
| 23,000 | 9 | 60 | 0 | 25 | 25 | 1 | 10 | Grid | 1325 | 30 | .. | Generating stations |
| 25,000 | 24 | 60 | 886 | 0 | 886 | 3 | 28.8 | Grid | 200 | 60 | .. | Generating stations |
| 26,400 | 17 | 60 | 277 | 18 | 295 | 2 | 6 | Grid | 2000 | 60 | .. | Generating stations |
| | 18 | 60 | .. | .. | ? | 2 | 150 | Water | 200 | 2 | .. | Generating stations |
| 66,000 | 1 | 25 | 200 | 0 | 200 | 1 | 58 | Grid | 200 | 30 | .. | Generating stations |
| | 17 | 25 | 85 | 0 | 85 | 1 | ? | Grid | 2000 | 60 | .. | Generating stations |
| | 23 | 60 | 161 | 0 | 161 | 2 | 63.5 | Grid | 600 | 10 | 600° C | Generating stations |
| 110,000 | 31 | 25 | 802 | 0 | 802 | 1 | 100.0 | Water | .. | .. | .. | |

TABLE IV-B—TRANSMISSION AT HIGHER THAN GENERATED VOLTAGE
SYSTEMS GROUNDED BY SPECIAL METHODS

| Voltage | No. of Company | Frequency | Miles Overhead | Miles Underground | Miles Total | No. of Grounds | Description of Ground |
|---|---|---|---|---|---|---|---|
| 44,000 | 3 | 60 | 100 | 0 | 100 | 1 | Peterson coil placed in neutral of transformer bank at generating station. |

TABLE V-A. CALCULATIONS TO ANALYZE DESIGNING OF GROUNDING RESISTANCE

| Voltage | No. of company | Frequency | Number of grounds | Ohms per ground | Calculation of Factor $k$: $25\,L\,b$ | $L\,a + 25\,L\,b$ | $R\,f$ | $k/10^6$ | Maximum current all grounds. Connections in parallel |
|---|---|---|---|---|---|---|---|---|---|
| 7500 | 19 | 60 | 1 | 2 | 3,775 | 3,775 | 120 | 0.45 | 2250 |
| 11,000 | 11 | 60 | 1 | 4 | .. | .. | .. | .. | 1590 |
| | 23 | 60 | 1 | 15 | 3,775 | 3,935 | 900 | 3.55 | 425 |
| 12,000 | 6 | 60 | 3 | 2.75 | 18,725 | 18,747 | 55 | 1.03 | 4620 |
| 13,200 | 17 | 60 | 1 | 3 | 2,120 | 2,266 | 180 | 0.41 | 2540 |
| | 19-20 | 60 | 2 | 8 | 4,150 | 4,150 | 240 | 0.99 | 1910 |
| | 22 | 60 | 1 | 5 | 0 | 25 | 300 | 0.01 | 1520 |
| | 36 | 60 | 1 | 4 | 4,250 | 4,702 | 240 | 1.13 | 1900 |
| 13,800 | 3 | 60 | 2 | 4 | 8,725 | 8,796 | 120 | 1.06 | 4000 |

TABLE V-B. CALCULATIONS TO ANALYZE DESIGN OF GROUNDING RESISTANCE

| Voltage | No. of company | Frequency | No. of grounds | Ohms per ground | Calculation of Factor $k$: 25 $L\,b$ | $L\,a + 25\,L\,b$ | $R\,f$ | $k/10^6$ | Maximum current all grounds. Connections in parallel |
|---|---|---|---|---|---|---|---|---|---|
| 22,000 | 23 | 60 | 7 | 15 | 0 | 172 | 129 | 0.02 | 5950 |
| 23,000 | 9 | 60 | 1 | 10 | 625 | 625 | 600 | 0.38 | 1330 |
| 25,000 | 24 | 60 | 3 | 28.8 | 0 | 886 | 576 | 0.51 | 1500 |
| 26,400 | 17 | 60 | 2 | 6 | 450 | 727 | 180 | 0.13 | 5100 |
| 66,000 | 1 | 25 | 1 | 58 | 0 | 200 | 1450 | 0.29 | 660 |
| | 23 | 60 | 2 | 63.5 | 0 | 161 | 1900 | 0.31 | 600 |
| 110,000 | 31 | 25 | 1 | 100 | 0 | 802 | 2500 | 2.00 | 1100 |

TABLE VI-A. TRANSMISSION AT GENERATED VOLTAGES
DATA ON CHANGES IN GROUNDING METHOD AND COMPARATIVE PERFORMANCE

| Voltage | Company | Present method of grounding | Change in type of ground | Is present method of grounding satisfactory | Factors determining magnitude of resistance, if used | Trouble experienced with resistance |
|---|---|---|---|---|---|---|
| 6000 | 36 | 7 ohm resistance in gen. neutral | .. | Yes | Operation of relays | None |
| 6600 | 19 | Resistance in generator neutral | Free neutral to resistance | Yes | Operation of relays and limited disturbance | None |
| 7800 | 19 | 2 ohm resistance | .. | Yes | Current equal to 125 per cent of full load on generator | None |
| 9000 | 6 | 2-1/2 ohm resistance in generators | Free to resistance | Yes | Limitation of damage | None |
| 11,000 | 11 | Dead grounded at substations | Free neutral to resistance ground | Relays do not operate as quickly as desired | Severity of faults<br>Operation of breakers | None |
| | 23 | 15 ohms at source | Ungrounded to dead ground to resistance ground | Fairly lower resistance may be installed | Minimum current to operate relays. Elimination of damage to equipment | |
| | 27 | Ungrounded | | Ungrounded system is unsatisfactory due to increased capacity | .. | |
| | 29 | Ungrounded | | Propose to change from free to grounded neutral | .. | |
| 12,000 | 6 | 3 ohms at generator | | Yes | Resistance in generator to limit current to 2000 amperes | |
| | 21 | 5 to 10 ohms—water | Free neutral to dead ground to resistance | Yes | Elimination of surges<br>Limitation of Damage<br>High resistance found unsatisfactory to prevent surges | |
| 13,200 | 1 | Dead ground at power and substations | Ungrounded to 10 ohm resistance, 10 ohms by gradual steps to dead dead ground | Not entirely | Capacity of system<br>Current necessary for proper breaker operation<br>Voltage strains on system | Resistance burnt up |
| | 17 | 3 ohms on generator neutral | .. | Yes | Operation of relays | |
| | 18 | 2 ohms on generator neutral | Ungrounded to 2 ohm resistance | Yes | Severity of faults<br>Operation of relays | |
| | 19 | 8 ohms on generator neutral | Ungrounded to 8 ohm resistance<br>30 second resistance to 10 min. resistance | Yes | Severity of faults<br>Operation of relays | Grid resistance burnt up four times because of divided ground current |
| 13,200 | 22 | 5 ohms in generator neutral | Ungrounded to resistance ground | Yes | Protection of machine<br>Operation of relays | None |
| | 25 | Ungrounded | | Ungrounded neutral unsatisfactory | .. | .. |
| | 32 | Dead grounded at generator | Ungrounded to dead ground | Yes | .. | .. |
| | 36 | Resistance in generator neutral | Free to 8 ohms to 4 ohms | Yes | Operation of relays | None |
| 13,800 | 3 | 4 ohms at generator | Dead to resistance | Yes | Magnitude of current in case of ground | .. |

TABLE VI-B. TRANSMISSION AT HIGHER THAN GENERATED VOLTAGES
DATA ON CHANGES IN GROUNDING METHODS AND COMPARATIVE PERFORMANCE

| Voltage | Company | Present method of grounding | Change in type of ground | Is present method of grounding satisfactory | Factors determining magnitude of resistance, if used | Troubles experienced with resistances |
|---|---|---|---|---|---|---|
| 22,000 | 27 | Ungrounded | .. | Ungrounded neutral unsatisfactory due to increased capacity of system | .. | |
| 23,000 | 9 | 10 ohms at generator | Dead ground to resistance | Yes | Severity of faults<br>Operation of breakers | None |
| 25,000 | 24 | 28.8 ohms at generator stations | Ungrounded to resistance ground | Not satisfactory with present relay installation | Elimination of surges<br>Protection of equipment | Broken grids |
| 26,400 | 17 | 6 ohms at generating stations | .. | Yes | Operation of relays | |
| | 18 | 150 ohms water at generating stations | Dead grounded to 150 ohms resistance | Not sufficient information to decide | Minimum ground current giving satisfactory relay operation | |
| 33,000 | 7 | Dead grounds at substation | Free neutral to dead ground | Yes | | |
| | 25 | Ungrounded | .. | Ungrounded neutral unsatisfactory because of surges | | |
| 33,000 | 27 | Ungrounded | .. | Ungrounded neutral unsatisfactory due to increased capacity | | |
| 44,000 | 2 | Reactance coil | Dead ground to reactance | Expect to ground all lines | | |
| | 5 | Dead ground at substations | Resistance to dead ground | Yes | | |
| 66,000 | 1 | 58 ohms at power station | Dead ground to free neutral to resistance ground. Concrete resistance to grid resistance | Yes | Current required to operate relays but not cause overload of transformers | Concrete resistance caused arcing upon passing current. Grid resistances melt when breakers fail to clear trouble |
| | 17 | Resistance grounded at power stations | | Yes | Operation of relays | |
| | 23 | 63.5 ohms at power plants | | Yes | | Grid resistance burnt up by hanging on of ground current |
| | 24 | Dead ground at power plant | | Ungrounded neutral unsatisfactory due to increase capacity | | |
| | 36 | Ungrounded | | | | |
| 100,000 | 4 | Dead grounded | Ungrounded to dead ground | | | |
| | 5 | Dead grounded | Resistance to dead ground | Yes | | |
| 110,000 | 31 | Dead grounded at power station | Ungrounded to 1000 ohm resistance to 100 ohm resistance | Yes | Elimination of surges and limitation of duty on breakers and transformers | High resistance of low capacity burnt up |

TABLE VII. GENERAL DATA—SUMMARY

| No. of company | Generating capacity kv-a. | Ungrounded | | | Grounded | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Voltage | Miles | Protection other than ground | Dead | | Resistance | | Special Schemes | |
| | | | | | Volts | Miles | Volts | Miles | Volts | Miles |
| 1 | 130,000 | | | | 13,200 | 180 | 66,000 | 200 | | |
| | | | | | 26,400 | 40 | | | | |
| 2 | 153,500 | 22,000 | 60 | | 44,000 | 240 | | | 44,000 | 100 |
| | | 44,000 | 80 | | 110,000 | 564 | | | | |
| 3 | 173,000 | 66,000 | 21 | | 25,000 | 20 | 13,800 | 424 | | |
| 4 | 252,000 | 50,000 | 895 | | 100,000 | 1100 | | | | |
| | | 66,000 | 355 | | | | | | | |
| 5 | 315,850 | 13,000 | 133 | | 44,000 | 709 | | | | |
| | | | | | 100,000 | 1489 | | | | |
| 6 | 523,000 | | | | | | 9000 | 396 | | |
| | | | | | 20,000 | 93 | 12,000 | 375 | | |
| | | | | | 22,000 | 27 | | | | |
| | | | | | 33,000 | 28 | | | | |
| 7 | 102,265 | 20,000 | 80 | | 33,000 | 657 | | | | |
| | | 33,000 | 93 | | | | | | | |
| 8 | 293,000 | | | | 24,000 | 937 | | | | |
| | | | | | 48,000 | 212 | | | | |
| 9 | 14,000 | | | | | | 23,000 | 25 | | |
| 10 | 124,750 | | | | 11,000 | 3596 | | | | |
| | | | | | 30,000 | 105 | | | | |
| | | | | | 66,000 | 910 | | | | |
| | | | | | 110,000 | 193 | | | | |
| 11 | 72,500 | 22,000 | 22 | | | | 11,000 | 77 | | |

TABLE VII. GENERAL DATA—SUMMARY (Continued)

| No. of company | Generating capacity kv-a. | Ungrounded | | | Grounded | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Dead | | Resistance | | Special Schemes | |
| | | Voltage | Miles | Protection other than ground | Volts | Miles | Volts | Miles | Volts | Miles |
| 12 | 174,200 | 17,500 | 88 | | | | | | | |
| | | 22,000 | 122 | | | | | | | |
| | | 44,000 | 305 | | | | | | | |
| | | 75,000 | 171 | | | | | | | |
| | | 140,000 | 518 | | | | | | | |
| 13 | 139,000 | 11,000 | 69 | | 110,000 | 144 | | | | |
| | | 33,000 | 61 | | Arc suppressors also used | | | | | |
| | | 66,000 | 29 | | on 110 kv. system | | | | | |
| 14 | 69,100 | | | | 33,000 | 105 | | | | |
| | | | | | 110,000 | 90 | | | | |
| 15 | 30,800 | 15,000 | 28 | | | | | | | |
| 16 | 288,750 | | | | 15,000 | 389 | | | | |
| | | | | | 30,000 | 179 | | | | |
| | | | | | 50,000 | 204 | | | | |
| | | | | | 60,000 | 1000 | | | | |
| | | | | | 150,000 | 480 | | | | |
| 17 | 117,000 | | | | | | 13,200 | 329 | | |
| | | | | | | | 26,400 | 295 | | |
| | | | | | | | 66,000 | 85 | | |
| 18 | 241,700 | 11,000 | 63 | Arc suppressor | 26,400 | ? | 13,200 | 661 | | |
| | | 13,200 | 115 | " " | | | 26,400 | ? | | |
| 19 | 612,500 | | | | | | 6600 | 416 | | |
| | | | | | | | 7800 | 151 | | |
| | | | | | | | 11,000 | 108 | | |
| | | | | | | | 13,200 | 166 | | |
| 20 | 277,800 | | | | | | 15,500 | 13 | | |
| 21 | 302,250 | 24,000 | 135 | | | | 12,000 | 170 | | |
| 22 | 38,400 | | | | | | 13,200 | 25 | | |
| | | | | | | | 11,000 | 311 | | |
| 23 | 238,000 | | | | | | 22,000 | 172 | | |
| | | | | | | | | 172 | | |
| | | | | | | | 66,000 | 161 | | |
| 24 | 145,000 | | | | 66,000 | 26 | 25,000 | 886 | | |
| 25 | 16,600 | 13,200 | 5 | | | | | | | |
| | | 33,000 | 23 | | | | | | | |
| 26 | 16,000 | 13,200 | 70 | | | | | | | |
| | | 15,000 | 45 | | | | | | | |
| | | 33,000 | 185 | | | | | | | |
| 27 | 80,500 | 11,000 | 55 | Frequency absorber | | | | | | |
| | | 22,000 | 94 | on cable system | | | | | | |
| | | 33,000 | 90 | | | | | | | |
| 28 | 60,000 | | | | 55,000 | 344 | | | | |
| | | | | | 87,000 | 224 | | | | |
| | | | | | 100,000 | 298 | | | | |
| 29 | 17,700 | 11,000 | 315 | | 66,000 | 72 | | | | |
| 30 | 326,200 | 22,000 | 217 | | 17,000 | 327 | | | | |
| | | | | | 60,000 | 2042 | | | | |
| | | | | | 110,000 | 515 | | | | |
| 31A | 267,000 | 13,200 | 50 | | | | 110,000 | 802 | | |
| | | 26,400 | 240 | | | | | | | |
| 31B | 21,200 | | | | 110,000 | 75 | | | | |
| 31C | 9950 | 22,000 | 580 | | | | | | | |
| 32 | 92,000 | | | | 13,200 | 121 | | | | |
| 33A | 12,000 | 66,000 | 175 | | 132,000 | 76 | | | | |
| | | 24,000 | 70 | | | | | | | |
| 33B | 35,700 | 66,000 | 292 | | | | | | | |
| 33C | 145,000 | | | | 66,000 | 180 | | | | |
| | | | | | 132,000 | 110 | | | | |
| 33D | 34,000 | 33,000 | 115 | | | | | | | |
| 34 | 78,000 | 13,200 | 92 | | 66,000 | 460 | | | | |
| | | 19,000 | 68 | | Experimenting with arc | | | | | |
| | | 44,000 | 89 | | suppressor | | | | | |
| 35 | 55,600 | 13,200 | 28 | | | | | | | |
| 36 | 276,000 | 66,000 | 31 | | 6,000 | 10 | | | | |
| | | | | | 13,200 | 203 | | | | |

SUMMARY

Number of Companies 36

Total Capacity 6,371,815 kv-a.

Number of Systems....................108
" " " Ungrounded.................. 43
" " " Dead Grounded............. 41
" " " Resistance Ground......... 25
" " " Specially Grounded......... 1

Mileage.....................31,308
" Ungrounded........... 6,385
" Dead Grounded........18,475
" Resistance Ground..... 6,448
" Specially Grounded.... 100

Ave. Mil. per System.................290
" " " Ungrounded.............148
" " " Dead Grounded..........450
" " " Resistance...............258
" " " Specially Grounded.......100

TABLE VIII—KEY TO COMPANIES SUBMITTING INFORMATION

| Number of Company | Name of City | Name of Company |
|---|---|---|
| 1 | Baltimore, Md. | Consolidated Gas, Elec. Light and Power Co. and Pennsylvania Water and Power Co. |
| 2 | Birmingham, Ala. | Alabama Power Co. |
| 3 | Boston, Mass. | Edison Electric Illuminating Co. |
| 4 | Butte, Mont. | Montana Power Co. |
| 5 | Charlotte, N. C. | Southern Power Co. |
| 6 | Chicago, Ill. | Commonwealth Edison Co. |
| 7 | Chicago, Ill. | Public Service Elec. Co. of Northern Illinois |
| 8 | Detroit, Mich. | Detroit Edison Co. |
| 9 | Fall River, Mass. | Fall River Electric Lighting Co. |
| 10 | Fresno, Cal. | San Joaquin Light & Power Co. |
| 11 | Hartford, Conn. | Hartford Electric Light Co. |
| 12 | Jackson, Mich. | Consumers Power Co. |
| 13 | Keokuk, Iowa | Mississippi River Power Co. |
| 14 | Los Angeles, Cal. | Department of Public Service |
| 15 | Los Angeles, Cal. | Los Angeles Gas and Electric Corp. |
| 16 | Los Angeles, Cal. | Southern California Edison Co. |
| 17 | Milwaukee, Wis. | Milwaukee Electric Railway and Light Co. |
| 18 | Newark, N. J. | Public Service Electric Co. |
| 19 | New York, N. Y. | New York Edison Co. |
| 20 | New York, N. Y. | United Electric Light & Power Co. |
| 21 | Niagara Falls, N. Y. | Niagara Falls Power Co. |
| 22 | Pawtucket, R. I. | Blackstone Valley Gas and Electric Co. |
| 23 | Pittsburgh, Pa. | Duquesne Light Co. |
| 24 | Pittsburgh, Pa. | West Penn. Power Co. |
| 25 | Port Arthur, Tex. | Eastern Texas Electric Co. |
| 26 | Poughkeepsie, N. Y. | Central Hudson Gas and Electric Co. |
| 27 | Providence, R. I. | Narragansett Electric Lighting Co. |
| 28 | Riverside, Cal. | Nevada-California Power Co. |
| 29 | San Diego, Cal. | San Diego Cons. Gas and Electric Corp. |
| 30 | San Francisco, Cal. | Pacific Gas and Electric Co. |
| 31 | Toronto, Ont. | Hydro-Electric Power Commission |
| 32 | Washington, D. C. | Potomac Power Co. |
| 33 | Wheeling, W. Va. | American Gas and Electric Co. |
| 34 | Worcester, Mass. | New England Power Co. |
| 35 | Worcester, Mass. | Worcester Electric Light and Power Co. |
| 36 | Philadelphia, Pa. | Philadelphia Electric Co. |
| 37 | Buffalo, N. Y. | Buffalo General Electric Co. |

## NATIONAL MOTIVE POWER COMMISSION FOR MEXICO

The Mexican Government has announced the organization of a national commission of motive power (Comision Nacional de Fuerza Motriz), for the organization, development, planning, and supervision of the commercial exploitation of the natural-power resources of the Republic. Studies will be made of the legislation in other countries relative to the developments of hydroelectric power and the generation and sale of electrical energy.

The commission's program includes advising the Government concerning which bodies of water should be withheld from power exploitation; division of the principal rivers of the country into sections according to their respective possibilities for power or irrigation development; revision of the Federal or local tax laws which may hinder the establishment and operation of hydroelectric plants; study of the advisability of abolishing or modifying the present Federal tax on water concessions; study of the desirability of preserving, restricting, or extending the privileges generally granted to power companies; assistance to power companies in obtaining subventions from the Government when it is considered that they are for the public interest; and the study, in cooperation with local authorities, of the desirability of electrifying certain railroad and street-car lines.

It is planned also to exercise control and supervision over hydroelectric plants already functioning, with a view to possibly revising the concessions which authorized the establishment of these plants. Similar plans will probably be developed where the energy is generated from sources other than hydraulic.

## BRITISH REGULATIONS FOR RADIO EQUIPMENT

While there are practically no restrictions on importing radio products into the United Kingdom, or any restriction on their sale, the purchaser, can not legally operate a wireless set unless he possesses an "experimental" license or a "broadcasting" license, both of which are issued by the British Postmaster General under certain arrangements with the British Broadcasting Co. Any person, in order to obtain an experimental license, which costs 10s. a year, must convince the British Postmaster General that he or she wishes to experiment with a view to improving wireless apparatus, or is desirous of inventing something in connection therewith. In practise this latter is a very difficult task for the average person to accomplish, as in his application for an experimental license he is expected to answer a number of questions of a technical nature, which naturally can only be done by a person possessing a fair knowledge of the subject. It will be seen, therefore, that the number of experimental licenses must of necessity be limited. It is reported, however, that quite a number of people have made application for experimental licenses and that an appreciable number are held up at the present time pending the issuing of a suggested new license, to be known as the "constructor's" license, which, it is expected, will enable people with no technical knowledge to assemble wireless sets and use them without any experimental purpose in view.

The "broadcasting" license is also obtainable on payment of 10s. at British post offices within the area in which the user of the wireless set resides. Such a license necessitates the exclusive use of a set purchased complete from the makers, and the set must be stamped with the letters "B. B. C."—the initials of the British Broadcasting Co. This latter indorsement signifies that all royalties and patent fees have been paid.

# A General Consideration of T- and Pi-Type Artificial Electric Lines

## In Connection with a Proposed Compensated Pi-Line

BY H. NUKIYAMA
Associate, A. I. E. E.
Prof. of Elec. Eng., Tohoku Imperial University, Japan

and

K. OKABE
Lecturer at Tokohu Imperial University, Japan

***Review of the Subject.***—*A theory of the general artificial electric line circuit, including the T-and $\pi$-lines as its special case, is here laid down. This theory is applied to the determination of a simple method for designing a compensated $\pi$-type artificial electric line whose electrical characteristics can be more closely approximated to the actual uniform line than a common T-line or $\pi$-line, when required to work, not at a single frequency, but over a definite range of frequencies.*

---

It is well known that $T$-type or $\pi$-type artificial electric lines may be made externally equivalent to a uniform line, but they represent different characteristics at other frequencies. When compared with a uniform line, the characteristics of the $T$-line and $\pi$-line are in opposition to each other if they are represented by a complex number. (Bib. 3.)

In the same way that we can construct an artificial line which has better frequency characteristics than the

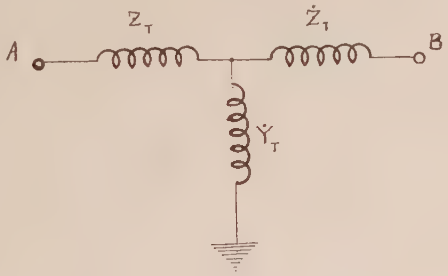



Fig. 1—T-Line Section

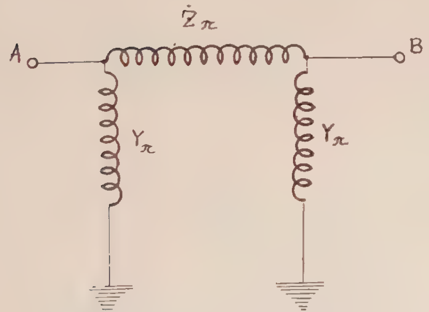



Fig. 2—Pi-Line Section

$T$-line or $\pi$-line, by combining these two lines properly, we may obtain a similar result by using such artificial lines as are shown in Fig. 3. This construction is intermediate between that of the $T$-line (Fig. 1) and $\pi$-line (Fig. 2), and this type of artificial line will here be called the "Compensated $\pi$-line."

### I. The Theory of the Compensated $\pi$-Line

In Fig. 3, $Z_{C\pi}$, $Z_\pi$ and $Z_C$ represent impedance between $A\,B$, $C\,D$ and $D\,B$ respectively. $Z_C$ will be called the "Compensating impedance." $Y_{C\pi}$ represents the shunt admittance.

We will consider the compensated $\pi$-line which is to represent the uniform line (Fig. 4). In Fig. 4, $Z_0$ and $\theta_\theta$ denote the surge impedance and the total hyperbolic

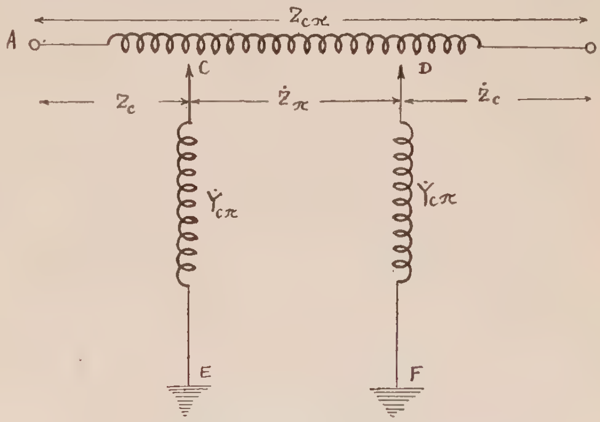



Fig. 3—Compensated Pi-Line Section

angle (vector attenuation constant) respectively. We put

$$\beta = \frac{2\,Z_c}{Z_{C\pi}} \qquad \text{numeric } \angle \qquad (1)$$

which represents the degree of compensation. In order to have the conditions such that the compensated

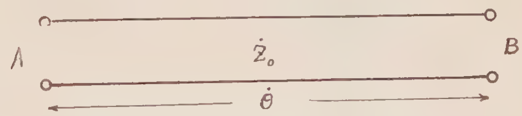



Fig. 4—Conjugate Uniform Line

$\pi$-line and the uniform line have the same electrical behavior at the terminals $A$ and $B$, we will consider the case when the receiving end is short-circuited. The currents at the receiving end $B$, and at the sending end $A$, are represented by $I_B$ and $I_A$. In Fig. 3 we get

$$I_A = [1 + Y_{C\pi}\,(Z_\pi + Y_{C\pi}\,Z_C\,Z_\pi + 2\,Z_C)\,]\,I_B \qquad \text{amp. } \angle \qquad (2)$$

*Presented at the Annual Convention of the A. I. E. E., Swampscott, Mass., June 25-29, 1923.*

In Fig. 4, we get (Bib. 1, 2)

$$I_A = I_B \cosh \theta \qquad \text{amp. } \angle \qquad (3)$$

According to the condition of equivalency, we have

$$\cosh \theta = 1 + Y_{C\pi} (Z_\pi + Y_{C\pi} Z_C Z_\pi + 2 Z_C) \qquad \text{numeric } \angle \qquad (4)$$

From the equation (1)


Fig. 5—β-Plane

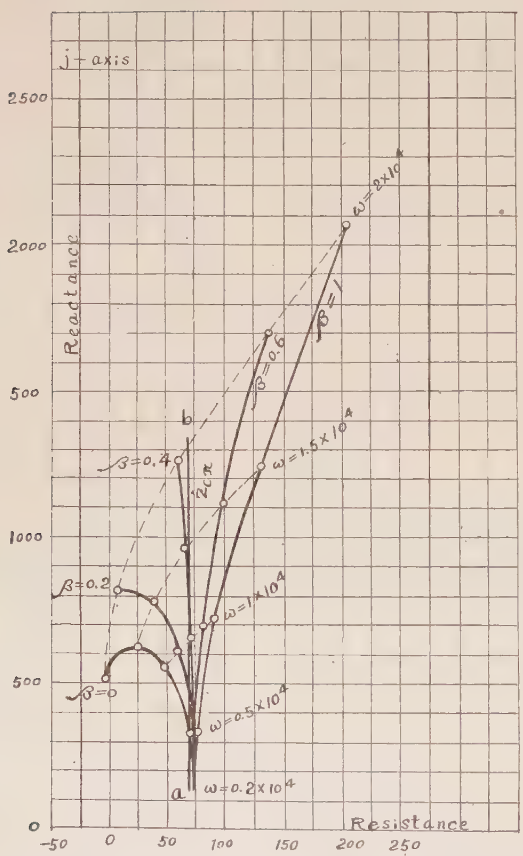



Fig. 6—Value of $Z_{C\pi}$ for Different Values of β

$$\left.\begin{aligned} Z_C &= \frac{\beta Z_{C\pi}}{2} \\ Z_\pi &= (1-\beta) Z_{C\pi} \end{aligned}\right\} \text{ohm } \angle \qquad (5)$$

are obtained. By (4) and (5), we have

$$\cosh \theta = 1 + Y_{C\pi} Z_{C\pi} \left\{ 1 + \frac{(1-\beta)\beta}{2} Y_{C\pi} Z_{C\pi} \right\} \qquad \text{numeric } \angle \qquad (6)$$

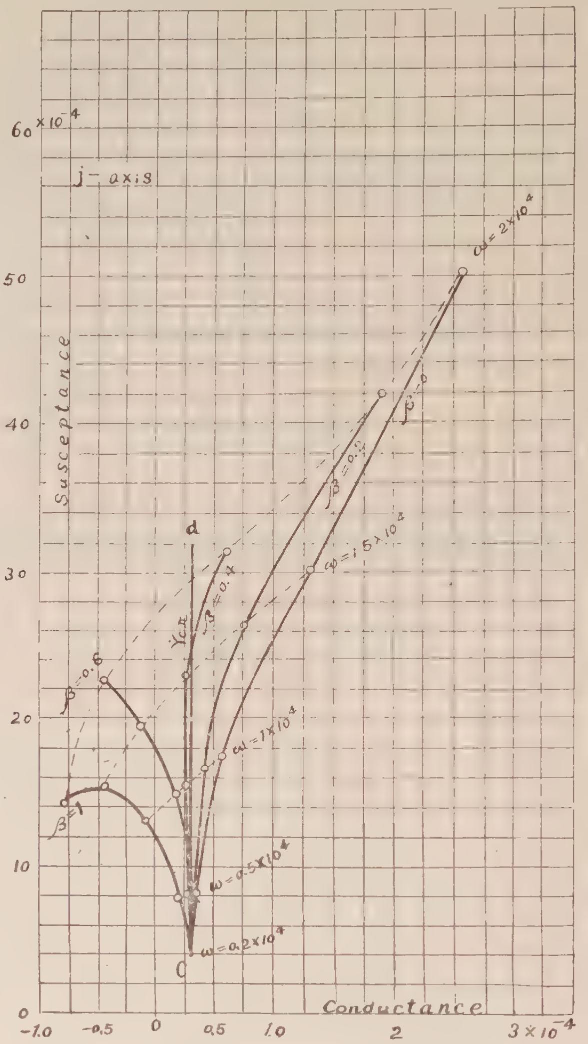



Fig. 7—Value of $Y_{C\pi}$ for Different Values of β

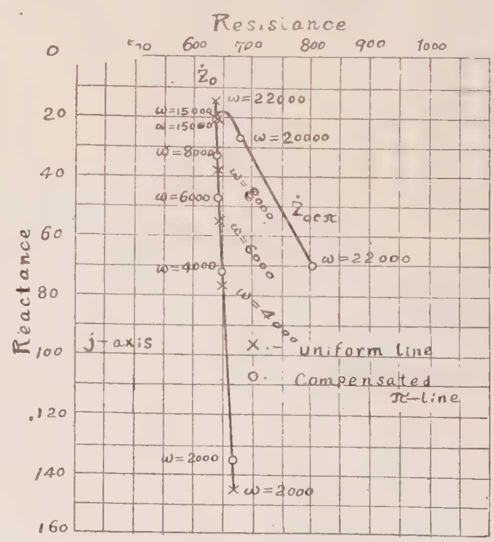



Fig. 8—Comparison of the Surge Impedance of Actual and Compensated Pi-Type Artificial Line

Next we will consider the case when the receiving end is freed. The voltage at the receiving end and the current at the sending end are represented by $V_B$ and $I_A$. In Fig. 3 we obtain

$$I_A = (2 + Y_{c\pi} Z_\pi)\, Y_{c\pi} V_B \qquad \text{amperes} \angle \qquad (7)$$

In Fig. 4 we have (Bib. 1, 2)

$$I_A = V_B/(Z_0 \sinh \theta) \qquad \text{amperes} \angle \qquad (8)$$

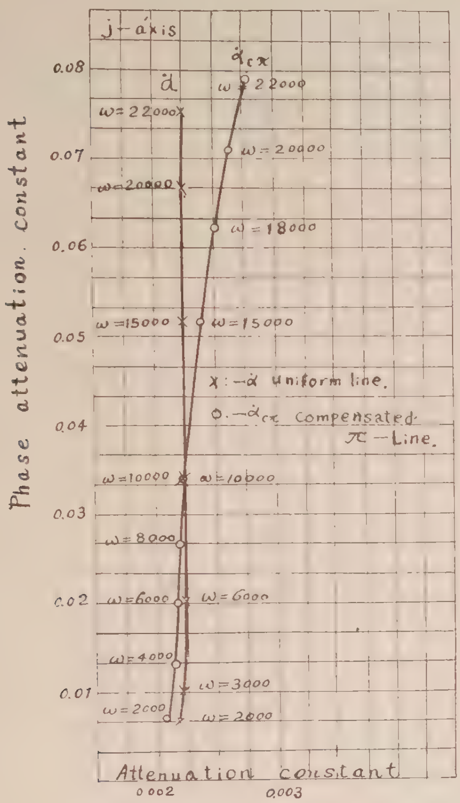



Fig. 9—Comparison of the Linear Hyperbolic Angle of Actual and Compensated Pi-Type Arftificial Line

From (5), (7) and (8)

$$\frac{\sinh \theta}{Z_0} = [2 + (1-\beta)\, Y_{c\pi} Z_{c\pi}]\, Y_{c\pi} \qquad \text{mho} \angle \qquad (9)$$

is obtained by the condition of equivalency. Solving the values of $Z_{c\pi}$ and $Y_{c\pi}$ from (6) and (9) we get

$$Z_{c\pi} = \frac{2\,(\sinh \theta/\theta)\, Z}{\{1 - \beta + \beta \cosh \theta + \sqrt{\beta^2 + 2\beta(1-\beta)\cosh\theta + (1-\beta)^2}\}} \qquad \text{ohm} \angle \qquad (10)$$

$$Y_{c\pi} = \left\{\frac{\tanh(\theta/2)}{\theta/2}\right\} \frac{Y}{2(1-\beta)} \{1 - 2\beta + \sqrt{\beta^2 + 2\beta(1-\beta)\cosh\theta + (1-\beta)^2}\} \qquad \text{mho} \angle$$

where $Z$ and $Y$ represent the total impedance and the total admittance of the conjugate uniform line. The following relations being well known

$$\left.\begin{aligned} \theta &= \sqrt{ZY} \ \text{hyps.} \angle \\ Z_0 &= \sqrt{Z/Y} \ \text{ohm} \angle \end{aligned}\right\} \qquad (11)$$

we can design the compensated $\pi$-line by equation (10) assigning an arbitrary value to the compensating factor $\beta$. Solving (6) and (9) with respect to $\theta$ and $Z_0$, we get,

$$\theta = 2 \sinh^{-1} \sqrt{\frac{Y_{c\pi} Z_{c\pi}}{2}\ 1 + \frac{(1-\beta)\beta}{2} Y_{c\pi} Z_{c\pi}} \qquad \text{hyps.} \angle$$

$$Z_0 = \sqrt{\frac{Z_{c\pi}}{Y_{c\pi}}} \left\{ \frac{\sqrt{1 + 0.5\,(1-\beta)\,\beta\, Y_{c\pi} Z_{c\pi}}}{1 + 0.5\,(1-\beta)\, Y_{c\pi} Z_{c\pi}} \times \cosh(\theta/2) \right\} \qquad \text{ohm} \angle \qquad (12)$$

So that the constants of the conjugate uniform line can be obtained from the constants of the compensated $\pi$-line, $Z_{c\pi}$, $Y_{c\pi}$ and $\beta$.

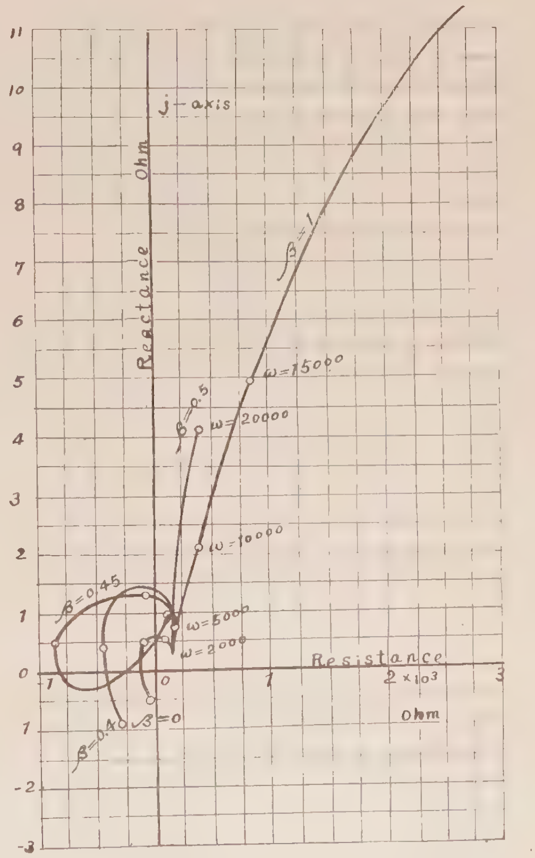



Fig. 10—Value of $Z_{c\pi}$ for 60-Cycle Section

## II. The Relation between the Correcting Factor and the Compensating Factor

We can understand easily by (10) that the series impedance and the shunt admittance of the compensated $\pi$-line are obtained by multiplying the correcting factors

$$K_1 = \frac{2 \sinh \theta / \theta}{\{1 - \beta + \beta \cosh \theta + \sqrt{\beta^2 + 2\beta\,(1 - \beta \cosh \theta + (1 - \beta)^2}\}} \quad \text{numeric } \angle$$

$$K_2 = \frac{\tanh (\theta/2) \div \{(1 - \beta)(\theta/2)\}}{1 - 2\beta + \sqrt{\beta^2 + 2\,\beta\,(1 - \beta) \cosh \theta + (1 - \beta)^2}} \quad \text{numeric } \angle \tag{13}$$

into the series impedance and half the shunt admittance of the uniform line respectively. These correcting factors are not only functions of $\theta$ (functions of frequency accordingly), but are also functions of $\beta$.

In the case of absence of $Z_c$, *i. e.*, $\beta = 0$, it is a pure $\pi$-line. We obtain the following correcting factors by putting $\beta = 0$ in (**13**),

$$\left.\begin{aligned} K_{1(\beta=0)} &= \frac{\sinh \theta}{\theta} \quad \text{numeric } \angle \\ K_{2(\beta=0)} &= \frac{\tanh (\theta/2)}{\theta/2} \quad \text{numeric } \angle \end{aligned}\right\} \tag{14}$$

which are the well-known correcting factors for the $\pi$-line. On the contrary, the pure $T$-line is obtained in the case $Z_\pi = 0$. We get the following correcting factors by putting $\beta = 1$ in (**13**).

$$\left.\begin{aligned} K_{1(\beta=1)} &= \frac{\tanh (\theta/2)}{\theta/2} \quad \text{numeric } \angle \\ K_{2(\beta=1)} &= \frac{\sinh \theta}{\theta} \quad \text{numeric } \angle \end{aligned}\right\} \tag{15}$$

which are the well known correcting factors of a $T$-line.

As mentioned above, the compensated $\pi$-line is to be considered as the general type of artificial line, including both $\pi$-lines and $T$-lines. The complex values allowed for $\beta$ are limited from the physical point of view. If negative resistance is not allowed, the following relation must obtain:

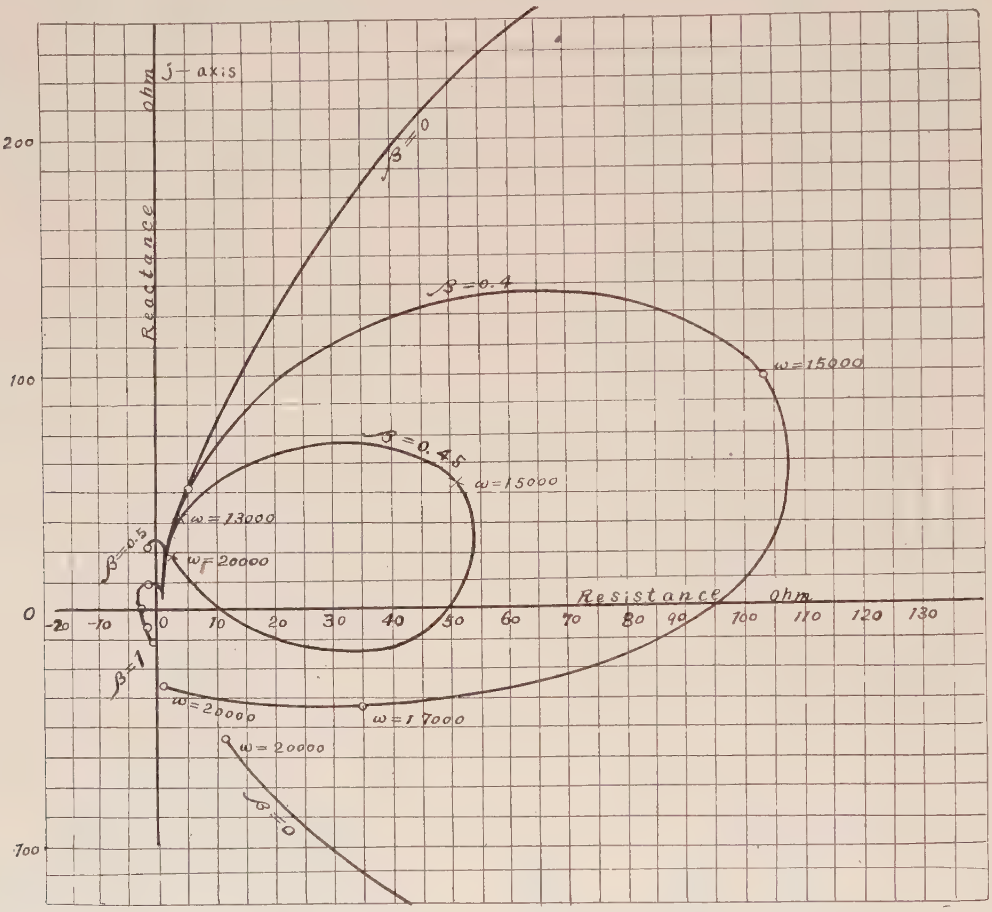



Fig. 11—Value of $Y_{c\pi}$ for 60-km. Section

$$0 \leqq \text{real part of } \beta\, Z_{c\pi} \leqq \text{real part of } Z_{c\pi} \text{ ohm } \angle \tag{16}$$

In the $\beta$-plane in Fig. 5, the domain of $\beta$ may be determined by (**13**) and (**16**). As a special case, we consider $\beta$ to be real. In this case the following relation holds:

$$-\pi/2 < \gamma < \pi/2 \text{ radian}$$

$\gamma$ being the slope of $Z_{c\pi}$. Therefore from (**16**), we get

$$0 \leqq \beta \leqq 1 \text{ numeric}$$

So that the value of $\beta$ must not be more than 1 nor less than zero on the real axis.

The general case when $\beta$ is complex, is not so simple, but in a practical case it will be convenient to study the nature of the correcting factors by trial, choosing proper

values for $\beta$ from a consideration of the physical construction of the artificial line.

## III. How to Design the Compensated $\pi$-Line

In the compensated $\pi$-line, resistances and inductances are connected in series for the impedance $Z_{c\pi}$ etc., and for the admittance $Y_{c\pi}$, condensers and resistances are connected in parallel, so that their frequency characteristics are the straight lines parallel to the imaginary axis. Not only so, but the imaginary parts are proportional to the frequencies. Hence, if we take such a value of $\beta$ that the frequency characteristics of $Z_{c\pi}$ and $Y_{c\pi}$ are similar to those above mentioned, the compensated $\pi$-line whose nature is approximately similar to that of the uniform line, may be obtained.

As an example, the following aerial telephone line will be calculated.

Copper wire, B. w. g. No. 8, distance between the centers of wires, 40 cm.

Series resistance $v = 2.494$ ohms/km.
Series self inductance $l = 0.0022$ henrys/km.
Leakage conductance $g = 10^{-6}$ mhos/km.
Shunt capacitance $c = 0.005285 \times 10^{-6}$ farads/km.

The compensated $\pi$-line which corresponds to the 30 km. section of the above line was calculated. The total series impedance and the total shunt admittance were obtained as follows:

$$Z = 30\,[2.494 + j\,\omega \times 0.0022] \quad \text{ohms} \angle$$
$$Y = 30\,[10^{-6} + j\,\omega \times 0.005285 \times 10^{-6}]\ \text{mhos} \angle$$

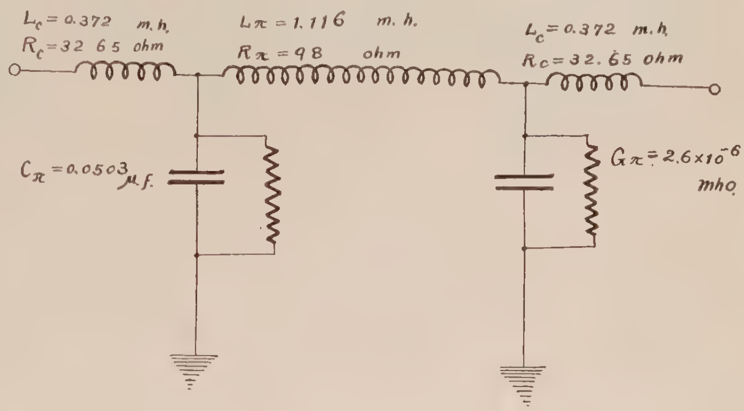



Fig. 12—Compensated Pi-Line for 3-km. Section of Standard Cable

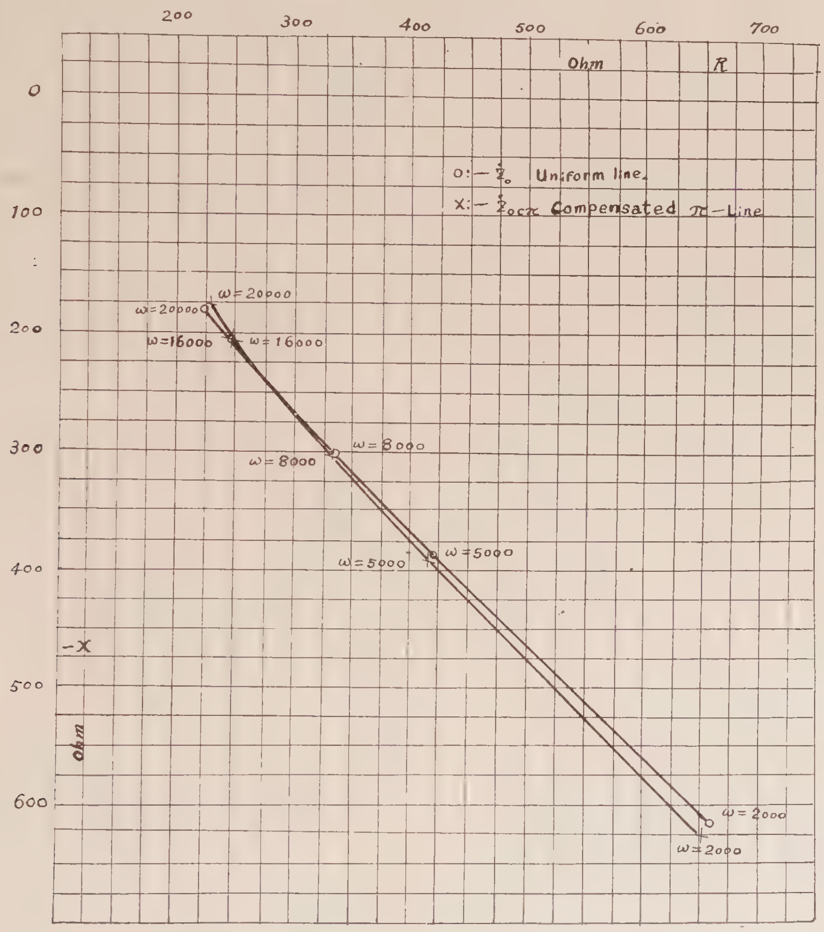



Fig. 13—Comparison of the Surge Impedance of Actual and Compensated Pi-Type Standard Cable

$Z_{c\pi}$ and $Y_{c\pi}$ are calculated for the various real values of $\beta$ (0, 0.2, 0.4, 0.6 and 1) in the range of frequencies between 2000 and 20,000 in angular velocity. The results are shown in Figs. 6 and 7. In the various values of $Z_{c\pi}$ and $Y_{c\pi}$, we see that those which cor-

respond to $\beta = 0.4$, are satisfactory, because the characteristic is nearly vertical and the imaginary parts are proportional approximately to the frequency. Then two straight vertical lines, $a\,b$ (Fig. 6) and $c\,d$ (Fig. 7) are drawn as a proper approximation to the characteristics of $Z_{c\pi}$ and $Y_{c\pi}$. The constants of the compensated $\pi$-line were chosen so that the characteristics of $Z_{c\pi}$ and $Y_{c\pi}$ are $a\,b$ and $c\,d$. Thus we have

$R_{c\pi} = 70$ ohms $\qquad R_c = 0.2 \times 70$ ohms

$L_{c\pi} = 0.0645$ henries $\qquad L_c = 0.2 \times 0.0645$ henries

$G_{c\pi} = 3.2 \times 10^{-6}$ mhos $\qquad R_\pi = 0.6 \times 70$ ohms

$C_{c\pi} = 0.157 \times 10^{-6}$ farads $\qquad L_\pi = 0.6 \times 0.0645$ henries

The surge impedance $Z_{0c\pi}$ and the linear hyperbolic angle $\alpha_{c\pi}$ were calculated by (**12**). The corresponding values of the uniform line were also calculated by (II). The results of the calculation are given in Table I, Figs. 8 and 9. As shown by the table and the figures, the surge impedances and the linear hyperbolic angles of both lines coincide with each other approximately. Hence we can say that this compensated $\pi$-line agrees satisfactorily in all electrical respects with the uniform line. Moreover this type is convenient for calculation, since it is not a composite line as is the case of the combined $T$-$\pi$-type.

Similar calculations were made for the same telephone line, increasing the length of section to 60 km. The results are given in Figs. 10 and 11. In this case, it is difficult to choose the value of $\beta$ properly. If we cannot have $Z_{c\pi}$ and $Y_{c\pi}$ with the desired vertical characteristics etc. for the various values of $\beta$, the length of one section must be decreased.

As another example, it was found that the proper value of $\beta$ should be 0.4, for the 3-km. section of the

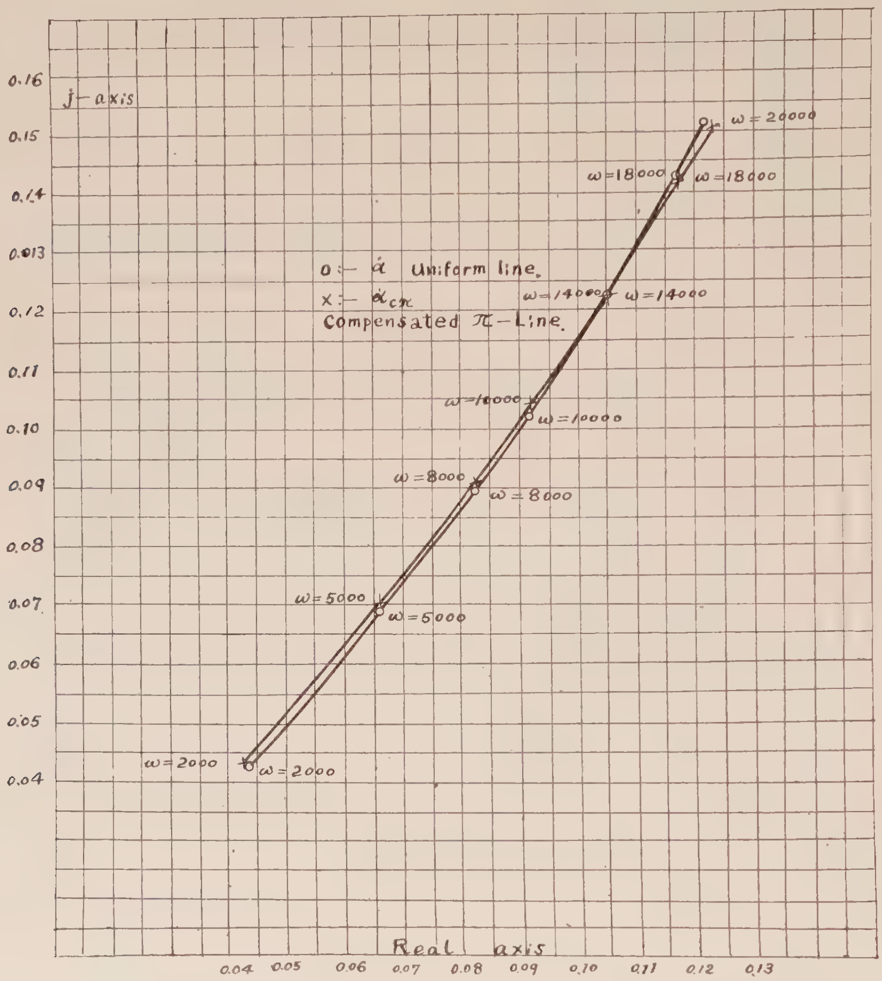



FIG. 14—COMPARISON OF THE LINEAR HYPERBOLIC ANGLE OF ACTUAL AND COMPENSATED PI-TYPE STANDARD CABLE

TABLE I.

LINEAR HYPERBOLIC ANGLE AND SURGE IMPEDANCE OF THE AERIAL LINE AND THE COMPENSATED $\pi$-TYPE ARTIFICIAL LINE

| $\omega$ | $\alpha \angle$ | $\alpha_{c\pi} \angle$ | $Z_0 \angle$ | $Z_{0c\pi} \angle$ |
|---|---|---|---|---|
| 2000 | $.00219 + j\,.00699$ | $.00210 + j\,.00686$ | $690\ \overline{\diagdown 12^\circ.07}$ | $685\ \overline{\diagdown 11^\circ.40}$ |
| 3000 | $.00223 + j\,.01035$ | .... | $666\ \overline{\diagdown 8^\circ.55}$ | .... |
| 4000 | $.00224 + j\,.01374$ | $.00217 + j\,.0134$ | $657\ \overline{\diagdown 6^\circ.56}$ | $653\ \overline{\diagdown 6^\circ.20}$ |
| 5000 | $.00224 + j\,.01715$ | .... | $653\ \overline{\diagdown 5^\circ.30}$ | .... |
| 6000 | $.00225 + j\,.02030$ | $.00218 + j\,.0202$ | $650\ \overline{\diagdown 4^\circ.45}$ | $645\ \overline{\diagdown 4^\circ.25}$ |
| 7000 | $.00225 + j\,.02392$ | $.00220 + j\,.0235$ | $649\ \overline{\diagdown 3^\circ.83}$ | $644\ \overline{\diagdown 3^\circ.60}$ |
| 8000 | $.00225 + j\,.02734$ | $.00222 + j\,.0270$ | $648\ \overline{\diagdown 3^\circ.35}$ | $641\ \overline{\diagdown 3^\circ.04}$ |
| 10,000 | $.00225 + j\,.03420$ | $.00222 + j\,.0340$ | $647\ \overline{\diagdown 2^\circ.69}$ | $644\ \overline{\diagdown 2^\circ.57}$ |
| 15,000 | $.00225 + j\,.05115$ | $.00243 + j\,.0515$ | $646\ \overline{\diagdown 1^\circ.82}$ | $646\ \overline{\diagdown 1^\circ.83}$ |
| 20,000 | $.00225 + j\,.0675$ | $.00267 + j\,.0707$ | $645\ \overline{\diagdown 1^\circ.35}$ | $680\ \overline{\diagdown 2^\circ.26}$ |
| 22,000 | $.00225 + j\,.0750$ | $.00278 + j\,.0792$ | $645\ \overline{\diagdown 1^\circ.23}$ | $801\ \overline{\diagdown 5^\circ.08}$ |

standard cable whose linear constants are

$$r = 54.7 \quad \text{ohms/km.}$$
$$l = 0.622 \quad \text{m. h./km.}$$
$$g = 3.11 \times 10^{-6} \quad \text{mhos/km.}$$
$$c = 0.0336 \quad \mu\,\text{f./km.}$$

The result is shown in Fig. 12 where the values of $Z_{0c\pi}$, $\alpha_{c\pi}$, $Z_0$ and $\alpha$ are compared in Figs. 13 and 14 and Table II. They coincide remarkably.

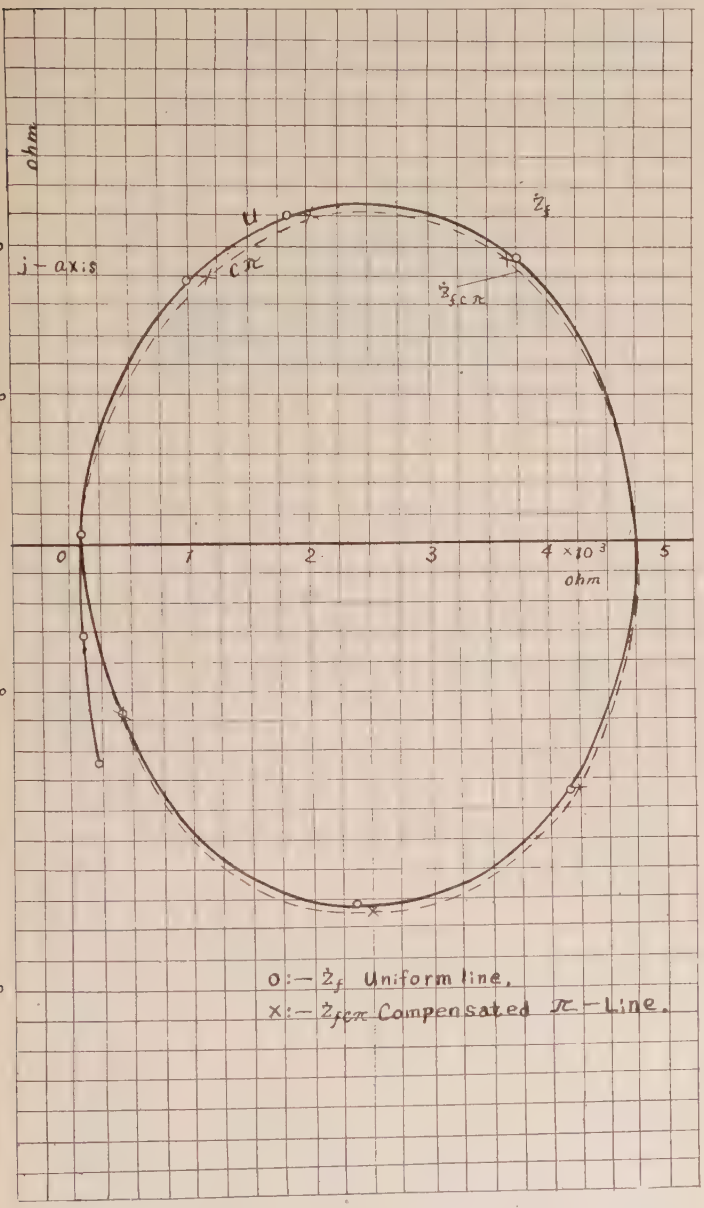



Fig. 15—Open-Circuit Impedance of 60-km. Artificial Line

TABLE II.

LINEAR HYPERBOLIC ANGLE AND SURGE IMPEDANCE OF THE STANDARD CABLE AND THE ARTIFICIAL LINE

| $\omega$ | $\alpha \angle$ | $\alpha_{c\pi} \angle$ | $Z_0 \angle$ | $Z_{0c\pi} \angle$ |
|---|---|---|---|---|
| 2000 | .04341 $+j$ .04238 | .0429 $+j$ .0428 | 901.7 $\overline{\backslash 43°1'25''}$ | 902 $\overline{\backslash 43°.96}$ |
| 5000 | .06654 $+j$ .06914 | .0659 $+j$ .0695 | 571 $\overline{\backslash 42°50'23''}$ | 570 $\overline{\backslash 43°.23}$ |
| 8000 | .0825 $+j$ .0892 | .0821 $+j$ .0900 | 452 $\overline{\backslash 42°3'30''}$ | 452 $\overline{\backslash 42°.23}$ |
| 10,000 | .0912 $+j$ .0102 | .0912 $+j$ .104 | 404 $\overline{\backslash 41°.47}$ | 406 $\overline{\backslash 41°.62}$ |
| 12,000 | .0985 $+j$ .112 | .0987 $+j$ .112 | 370 $\overline{\backslash 40°.90}$ | 370 $\overline{\backslash 41°.06}$ |
| 14,000 | .105 $+j$ .1225 | .1055 $+j$ .122 | 343 $\overline{\backslash 40°.30}$ | 344 $\overline{\backslash 40°.44}$ |
| 16,000 | .1114 $+j$ .1325 | .1104 $+j$ .1335 | 321.5 $\overline{\backslash 39°.68}$ | 323 $\overline{\backslash 39°.62}$ |
| 18,000 | .1166 $+j$ .1422 | .1166 $+j$ .1415 | 303.5 $\overline{\backslash 39°.06}$ | 305 $\overline{\backslash 39°.04}$ |
| 20,000 | .1215 $+j$ .1515 | .123 $+j$ .149 | 289 $\overline{\backslash 38°.44}$ | 289 $\overline{\backslash 37°.78}$ |

## IV. Comparison with other Types

If we choose the same sectional length, the compensated $\pi$-line is superior to the $T$-line (or $\pi$-line) of course, but the former is more complex than the latter in its construction. Therefore it is safe to compare it with the section of the $T$-line and $\pi$-line of half the length. In the above two representative cases, we found that the compensated $\pi$-line could be designed to be more

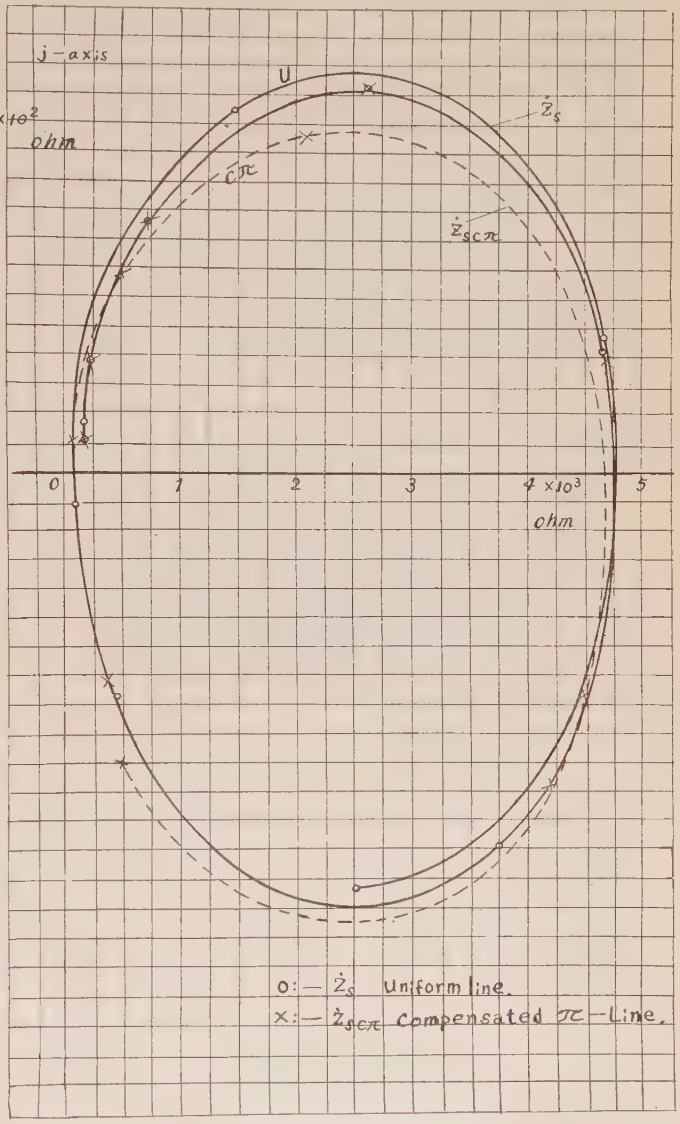



Fig. 16—Short-Circuit Impedance of 60-km. Artificial Line

satisfactory than the $T$-line or $\pi$-line of half length. Moreover, in these particular cases, this type gave better results experimentally than the combined $T$-$\pi$-type. In this case, the total length of the compensated $\pi$-line was taken as 60 km. and the length of the section was taken as 30 km. For the combined $T$-$\pi$-line, the total length was taken as 60 km., but for the length of each section 15 km. was chosen.

The short-circuit impedance of the compensated $\pi$-line $Z_{sc\pi}$, the open-circuit impedance of the same $Z_{fc\pi}$, the short-circuit impedance of the conjugate

uniform line $Z_{fs}$ and the open-circuit impedance of the same $Z_f$ are given in Figs. 15 and 16. These are to be compared with Figs. 14 and 15 in a previous paper. (Bib. 3).

## Bibliography


1. A. E. Kennelly. "The Application of Hyperbolic Functions to Electrical Engineering Problems."
2. H. Ho. Hado Sindo oyobi Hirai. P. 215.
3. H. Nukiyama and Y. Shoji. "The Combined $T$-$\pi$-Type Artificial Electric Line." *Denki Gakkai Zasshi*, June, 1922.
4. A. E. Kennelly. "Artificial Electric Lines."
5. A. E. Kennelly. "Tables of Complex Hyperbolic and Circular Functions."
6. A. E. Kennelly. "Chart Atlas of Complex Hyperbolic and Circular Functions.


---

# The Art of Sealing Base Metals Through Glass


BY WILLIAM G. HOUSKEEPER

Member, A. I. E. E.

Research Laboratories of the Am. Tel. & Tel. Co. and the Western Electric Company



***Review of the Subject.***—*Methods are described by which base metals may be sealed to and through glass, even though the metal and glass have different coefficients of thermal expansion. The method consists in providing a large surface of contact between the glass and the metal, and in so proportioning the metal that the stresses resulting from the difference in coefficients of expansion are less than the ultimate strength of the joint between glass and metal.*

*Four different types of seals are discussed:*

*First, the flattened wire seal for small electrical conductors.*

*Second, the ribbon seal for special purposes.*

*Third, the disk seal for commercial manufacture of seals for carrying currents of the order of 100 amperes.*

*Fourth, the tube seal in which metal and glass tubing are joined together.*


---

BOTH incandescent lamps and thermionic tubes consist of certain electrical elements enclosed in glass containing vessels. These vessels are exhausted to extremely low pressures and are then sealed up so that the vacuum may be maintained. It is necessary for leads to be provided which will make electrical contact with the electrodes within the exhausted vessel and which will permit of energizing these electrodes by means external to the vessel.

In the incandescent lamp, the electrode consists of a fine wire which is heated to a high temperature by passing current through it. For many years platinum was used as that part of the electrical conductor, passing through the walls of the glass enclosing vessel, which carried current to and from the filament. There are two reasons why platinum was used. First, it does not oxidize while the glass is being applied; consequently, the glass comes in contact with a clean surface of platinum and this was thought to be a desirable feature. Second, of the metals readily available, ten years ago, platinum was the only one which had a coefficient of expansion approximately the same as that of the lead glass in use at that time. Both lead glass and platinum have a coefficient of expansion approximately $9 \times 10^{-6}$ per deg. cent. Other metals, such as gold, silver, copper, iron, nickel, etc., have coefficients of expansion appreciably greater than that of glass. Consequently when attempts are made to cover round wires of these metals with glass, while good contact may be made with the glass hot, yet when the glass and wire cool down to room temperature, the metal contracts further than the glass, and separates from the glass, leaving very small openings between the wire and the glass, through which air readily enters the vacuum container. Consequently, it became axiomatic, in the incandescent lamp manufacturing industry, that the seal wire, as that portion of the conductor coming directly in contact with the glass was called, must have the same coefficient of expansion as that of the glass through which it passed. In consequence, we find that when the price of platinum increased enormously several years ago, platinum substitutes were offered for use, which had approximately the same coefficient of expansion as the platinum which they replaced.

Alloys of iron and nickel have the property of a varying coefficient of expansion, depending upon the relative proportions of the two component parts. An alloy may be obtained having practically any coefficient of expansion from zero to $14 \times 10^{-6}$ per deg. cent. One of the earliest platinum substitutes consisted of a core of a nickel iron alloy sheathed with platinum. Another substitute at present in use in the lamp manufacturing industry consists of an alloy core sheathed with copper and usually coated with dehydrated borax. In the substitution of either of these alloys for platinum, a larger diameter of the substitute wire is usually required. The alloy core is of considerably higher resistance than the platinum which it replaces. The copper sheathed wire in this respect is better than the platinum sheathed wire in that the copper is of lower resistance than the platinum. The high resistance is objectionable because, carrying the normal current, the wire heats and of course expands. If this expansion is sudden, that is, if the wire heats up before the surrounding glass, it is quite likely to split the glass from its internal wedging action. Consequently, it has been found advisable to

*Presented at the Annual Convention of the A. I. E. E., Swampscott, Mass., June 25-29, 1923.*

use only a short length of the platinum substitute and to weld copper wire to each end of the short length. The solid copper being a better heat conductor than the alloy wire itself, serves to take heat away from the wire and thus keep the resulting expansion at a minimum. Welding the copper wire to the substitute also serves to close up any small openings which may occur between the copper sheath and the alloy core which otherwise would give rise to very small leaks, developing after several days' or weeks' use. Thus we have the practically universal use of a round cylindrical wire which has approximately the same coefficient of expansion as that of glass, passing through the glass.

Fig. 1

Measurements made upon tungsten and molybdenum showed that they had coefficients of expansion approximately 1/3 that of the ordinary lead glass. The well-known Pyrex glass has approximately the same coefficient of expansion as that of tungsten. Thus satisfactory seals are made between tungsten and Pyrex glass through the intermediate use, however, of a second glass which seals satisfactorily to the tungsten and to which the Pyrex glass is, in turn, attached.

In the telephone plant, thousands of tiny incandescent lamps are used for indicating the condition of subscribers' lines. These lamps are approximately ¼ in. in diameter (6 mm.) and 1¾ in. long (4½ cm.).

Fig. 2

Several years ago, experiments were made to determine upon a practicable substitute if any, for the platinum used in these lamps. Trial lots of lamps were made up using various sizes of platinum and platinum substitutes at that time available. Exceedingly fine wires of copper and iron were tried, also copper wire covered with dehydrated borax was tried. As was expected, these showed slight leaks. No. 34 B & S gage copper wire was then prepared in a different way. Placed on an anvil, it was struck at right angles with the sharp edge of a hammer, thus flattening the wire locally to a section approximately 0.001 in. thick (0.025 mm.) and 0.030 in. wide (0.75 mm.). This wire was covered with dehydrated borax and the flattened portion placed within the glass. Tests showed that a seal made in this way was vacuum tight. An experimental machine was soon put together, using a cam-actuated hammer to flatten the wire, after which the wire was drawn by motor driven rolls through a borax coating bath and then through a dehydrating oven. Repeated tests showed that wire thus made sealed with lead glass without leaks. Larger sizes of wire were tried. Fig. 1 shows a 40-watt, 110-volt incandescent lamp made with the flattened copper. With the use of larger sizes of wire it became more and more difficult to flatten the wire by a single hammer blow. It was found that several successive blows were necessary. If the copper was not flattened sufficiently, separation occurred between the copper and glass. This separation could be seen easily, since it gave rise to interference fringes between the surface of the copper and the inner surface of the glass which had separated from the copper. Consequently, when it was found that wire, flattened to 0.002 in. (0.050 mm.) thick, 1/8 in. wide (3 mm.) made a tight seal with glass, it was reasoned that copper foil having these same dimensions should also make a satisfactory seal. This was tried and found to be so. Sheet copper, 0.002 in. thick (0.050 mm.) and 1/8 in. wide (3 mm.) covered with borax, made a tight seal with lead glass. Ribbons of copper foil 0.002 in. thick (0.050 mm.) and ¼ in. wide (6 mm.) were covered with

Fig. 3

borax and found to be tight. This thin ribbon, however, was mechanically weakened by oxidation outside of the seal. Consequently, ribbons were made from 0.004 in. (0.1 mm.) and 0.008 in. (0.2 mm.) sheet copper, ¼ in. wide (6 mm.), the ribbon being flattened locally at the sealing-in point, the increased thickness outside the seal making the ribbon mechanically stronger. All of these seals were covered with dehydrated borax.

The question arose as to the part played by the borax in the seal manufacture. Consequently, a seal was made with 0.002 in. (0.050 mm.) copper ribbon without borax. It was found that such a seal was tight, although the ribbon outside of the seal was exceedingly weak, due to oxidation. 0.004 in. ribbon (0.1 mm.), ¼ in. wide (6 mm.) apparently sealed in satisfactorily, though showing a slight leak under test. Ribbon 0.008 in. thick (0.2 mm.) by ¼ in. wide (6 mm.) when sealed in showed visible leaks along the edges of the ribbon, but not at the center. Fig. 2 shows a cross-section, not to scale, of such a seal. As previously explained, the leak is shown by interference rings produced in the small space between the glass and metal which are separated. We found that by tapering off the two edges of the strip by filing to a knife edge, tight

seals could be obtained between glass and 0.008 in. (0.2 mm.) copper ribbon, that is, the cross-section of the ribbon instead of being a rectangle, was made a parallelogram having two rather acute angles. Tight seals, using larger and larger sizes of copper were rapidly made in succession, until a ribbon 0.015 in. thick (0.38 mm.) and 1 in. wide (25.4 mm.) was sealed through glass without the use of borax, and without leaking. As before, the edges of the ribbon were filed to a knife edge. Such a seal is shown in Fig. 3 and a cross-section in Fig. 4.

The results of these preliminary experiments were so much at variance with belief and previous experience as to be open to considerable doubt as to the reliability of methods of test. Vacuum tight seals were, however, produced by different operators using material from different sources. As a result of these experiments and tests, a complete chemical and mathematical investigation was inaugurated as well as further experimental work either to prove or disprove the results of the initial experiments which have just been recorded.

In order that the explanation of the action of this seal, known as the ribbon seal, may be clear, the various steps in the manufacture will be explained somewhat in detail. A piece of 0.015 in. (0.37 mm.) sheet

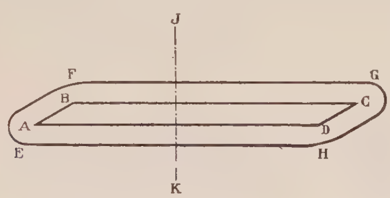



Fig. 4

copper is cut approximately 1 in. wide (25.4 mm.) by 4 in. long (10.1 cm.). The edges of the sheet copper for a length of approximately 1 in. (25.4 mm.) at the center are filed away so that the angle at the edge is approximately 8 deg. or 10 deg. A glass tube is provided, into the end of which it is desired to seal the ribbon. The end is flattened to provide an opening approximately 1 1/8 in. (28 mm.) by 1/8 in. (3 mm.). The sheet copper is then heated in the glass working fires for several seconds to a good red heat. It is then so placed within the end of the glass tube that the glass will come in contact with that section provided with the sharpened edges. The glass is pressed in contact with the ribbon and melted in place at as high a temperature as can be maintained without injury to the glass or the copper. It is then annealed and finally allowed to cool off. It will readily be seen that this operation is the exact parallel to that employed in sealing in platinum or platinum substitute wires.

In previous attempts to seal base metals through glass, in practically every instance round or nearly round wires were used, that is, wires were used in which the perimeter of the cross-section was the minimum possible for the area of cross-section. In the case of the copper ribbon seal, with a ribbon width of 1 in. (25.4 mm.) and thickness of 0.015 in. (0.37 mm.), the perimeter of the cross-section is very great compared to the perimeter of a circle of equal cross-section. In other words, for a given cross-section of metal, the ribbon affords a great deal more surface of contact between metal and glass than if a cylindrical conductor were used. Due to this great surface of contact, the stresses produced between metal and glass due to the difference in coefficients of expansion never become large enough to fracture either the joint between metal and glass or the glass itself.

In Fig. 4, $A$, $B$, $C$, $D$, is the cross-section of the copper ribbon, not to scale, and $E$, $F$, $G$, $H$ is the enclosing glass. We find that the copper ribbon is actually stretched in the direction $A\,C$. The cubical contraction of the copper is practically the same as that of an unrestrained piece. Consequently, copper contracts in thickness in the direction of the line $J\,K$ by that amount required by the cubical contraction of the copper. A few approximate figures may in this connection be interesting.

Assuming 525 deg. cent. as that temperature at which the glass commences to stretch the copper, room temperature of 25 deg. cent. coefficient of expansion for copper of $17 \times 10^{-6}$ per deg. cent., and coefficient of $9.1 \times 10^{-6}$ for glass, then the strain in a 1 in. length of copper will be approximately $(17.2 - 9.1) \times 10^{-6} \times 500 = 0.00405$ in. (0.1 mm.) Tests on soft copper show that this elongation corresponds approximately to a stress of 8700 pounds per square inch (612 kilograms per sq. cm.). The thickness of ribbon in the direction $J\,K$ of Fig. 4, being approximately 0.015 in. (0.37 mm.), the force necessary to stretch a 1 in. length of the seal will be approximately 131 lb. (59.4 kg.). This stress may be assumed to be carried as shear between the glass and the copper along planes $A\,B$ and $C\,D$. $A\,B$ and $C\,D$ are both approximately 5/32 in. (4 mm.) so that the shearing stress per square inch necessary to stretch the copper the required amount is approximately 840 pounds per square inch (59.1 kg. per sq. cm.). These figures are approximate only, since they neglect complications caused by the fact that the copper is in tension in three directions, in the directions $A\,C$ and $J\,K$, and also in a direction at right angles to the cross-section of the figure. However, the figures indicate the order of magnitude of the stresses involved.

The stretching of the copper has been directly measured on a somewhat different type of seal, the disk seal, which will be described later. There can be no doubt that the glass is sucked in by the copper in the direction $J\,K$. Two parallel spots were lapped on the glass surrounding such a seal and the distance, $J\,K$, on Fig. 3, carefully measured with a micrometer. The copper was then dissolved in nitric acid, leaving only the surrounding glass shell. Subsequent measurements showed that the glass had sprung outwardly a measurable amount.

Glass may be regarded as a more or less viscous

liquid. It has no definite melting point such as simple materials have. Upon heating it becomes more and more fluid until at the temperature at which it is applied to copper, it has the consistency of rather thin molasses. Glass at this temperature wets the copper, just as at room temperature, water will wet glass. Apparently as the hot glass and copper cool off, the adhesion of the glass to the copper is stronger than the cohesion within the glass, since in every case of a seal properly made, fracture will occur, not between the glass and copper, but in the glass itself, a thin film of glass being left adhering to the copper. Consequently the shearing strength of the joint between the glass and copper may be taken as equal to the shearing strength of the glass itself. Now the adhesion of the glass to the copper is entirely independent of the thickness of the copper or the thickness of the glass. The stresses, however, which the joint may be called upon to resist, are directly dependent upon the thickness of the glass or the copper or both. It is not possible to seal a heavy block of copper to a heavy block of glass since the stresses which the joint will be called upon to resist will be greater than the strength of the glass near the joint. However, it is entirely possible to seal a very thin section of either substance directly to the other; for example, a circular microscope cover glass may be melted to and will adhere to a large block of copper and a disk of sheet copper of approximately the same dimensions may be melted to a large block of glass. In both of these cases the stress which the joint between glass and copper is called upon to resist is less than the strength of the joint. Consequently, again referring to Fig. 4, we are led to the conclusion, which is amply sustained by experiment, that no matter what the metal, the angle $B\ A\ D$ may always be made sufficiently acute so that the stress between the metal and glass is always less than the shearing strength of the joint; that is, it is entirely possible to seal any metal through glass, provided that the glass wets the metal when hot and further provided that the metal does not melt at the temperature necessary for it to be wetted by the glass. Seals have been made between lead glass and base metals, such as, iron, brass, and silver. Copper is peculiarly satisfactory for this service, since soft copper passes its elastic limit at a comparatively low stress per square inch. Consequently, for a given width of ribbon, thicker copper may be used than if other metals are used. This is fortunate, because copper has good electrical and heat conductivity.

Referring again to Fig. 4, attempts have been made to determine the most desirable cross-section of the copper ribbon. The various methods of considering the stresses indicate approximately the same most desirable cross-section. It has been previously stated that the copper ribbon is stretched in the direction $A\ C$. This occasions a compressional stress in the glass $A\ F\ C$ and under compression this glass may be assumed a column, or, again, it has been stated that the glass $F\ C$ is drawn towards the glass $E\ D$ in the direction $J\ K$, by contraction of the copper ribbon in thickness. The glass $A\ F\ C$ then may be considered as a beam rigidly supported at both ends and deflected downwards under the load applied by the copper. In this case the deflection of the beam at each point throughout its length would be proportional to the thickness of the copper ribbon at that point. Under such conditions bending stresses will occur in the glass beam opposite points $A$ and $B$ at which points there is a change in rate of deflection. Preliminary consideration thus indicates the desirability of avoiding all corners on the cross-section of the ribbon.

Mr. T. C. Fry has made a very complete mathematical analysis of the stresses and strains occurring in a ribbon seal, in order to determine the best section of the copper, the "best section" being that having the maximum cross-section for a given width of ribbon. The curve indicated by Mr. Fry for cross-section of ribbon lies between the cosine curve of the glass considered as a column in compression and the curve of deflection of a beam rigidly fixed at both ends such that maximum fiber stress is nowhere exceeded. Thus in Fig. 4, the surface $A\ B$ should be curved and be approached by surface $A\ D$ tangentially, and surface $A\ B\ C$ should be a smooth curve without any sudden change in direction. The calculations, however, cannot be made with as great precision as might be desirable because of unknown factors in the calculation. We do not know the exact temperature at which solidification of the glass may be said to commence on cooling, nor do we know the elastic constants of glass and metals under various conditions of temperature and stress. Practically, if a ribbon seal fails, the angle at the edge is made sharper and a new seal made, rather than attempting to calculate the exact dimensions.

In the introductory paragraphs an advantage for platinum was claimed in that it did not oxidize and thus permitted closer contact between glass and metal. In the description of the seal manufacture it was stated that the copper ribbon was heated red hot before covering with glass. This heating of the copper ribbon of course oxidizes it and this oxide is not removed before being brought into contact with the glass. These two statements are at variance. As a matter of fact, perfectly good seals result when the copper has been oxidized as stated. If care is used to work in a reducing atmosphere and to use glass which does not reduce, as lead glass will, it is quite possible to make entirely satisfactory seals between glass and clean copper. Apparently, a reasonably thin coating of oxide does no harm, whatever, to the seal. When hot, this oxide is black, but as the seal cools off, the cupric oxide changes to cuprous oxide and it is this latter oxide which gives rise to the crimson color of the seal.

Fig. 5 shows a microphotograph of a section of the seal between copper and glass. The copper may be recognized from its etched surface. The black line

immediately next to the copper is a thin layer of cuprous oxide approximately 0.0003 in. in thickness (0.007 mm.) Immediately next to the thin layer of oxide will be seen a section of glass. This photograph is given to show the exceedingly close adhesion of the glass to the copper.

So far as we can find from consideration of the various factors entering the copper-lead glass seal, chemical reactions play a small and unimportant part. While certain reactions do occur, these are relatively slow and minute in comparison with the physical phenomena which make the seal possible.

Several interesting features of the ribbon seal are evident upon consideration. The copper ribbon with-

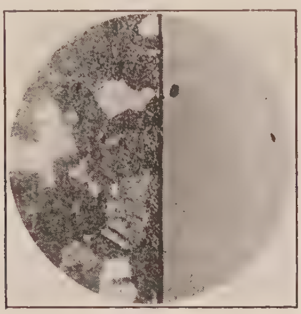


Fig. 5

in the glass, it will be remembered, is in tension in every direction. Heating the copper will thus initially reduce stresses because the copper will be expanded in the direction of the tension forces acting upon it. In other words, such a seal will not fail with sudden passage of current through the ribbon, because such heating as may occur in the ribbon actually lessens the stresses in the glass. A ribbon seal made from 0.008 in. sheet copper (0.4 mm.) and 7/16 in. wide (11 mm.) will continuously carry 40 amperes. It will, however, easily carry several hundred amperes for a short time. In fact it will carry enough current to make the ribbon visibly hot outside the seal. Again, various electrodes for

Fig. 6

use in vacuum apparatus may be formed from that portion of the ribbon within the enclosing chamber. Such an application may be seen in Fig. 6, showing the anode for a mercury rectifier tube made in one piece with the iron ribbon which passes through the glass member of the stem. Further applications may be easily imagined.

In the discussion of the ribbon seal it was assumed that the copper in Fig. 4 was stretched in the direction *A C* by the clamping effect of the glass upon the surfaces *A B* and *C D*. If this is the case, then it should be possible to construct a seal in which the glass comes only in contact with the copper ribbon at the edges of the ribbon and not along the center, that is, a seal such as that shown in Fig. 7 should be possible of construction. Next consider that Fig. 7 is a cross-section, not of a ribbon, but of a circular disk, taken at right angles to the plane of the disk along the diameter of the disk. Since, according to our assumption, glass does not touch the copper near the center of the disk, it

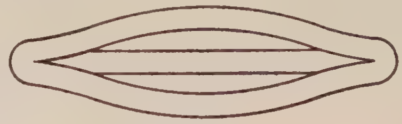


Fig. 7

makes no difference what form the glass assumes where it is not in contact with the copper; that is, it should be possible to seal a circular diaphragm into a glass tube in the manner shown in Fig. 8. It will be remembered that in the discussion of the ribbon seal, the edges of the ribbon were sharpened in order to prevent

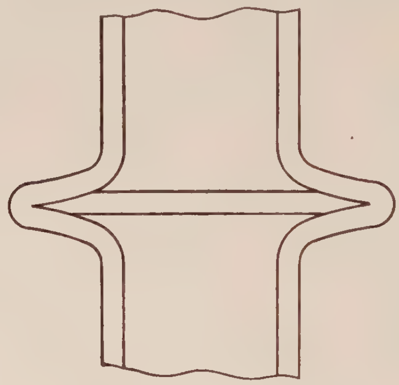


Fig. 8

separation of the ribbon and glass. If the disk has square edges, then whatever separation occurs between glass and copper will do no damage provided separation does not extend to the inside of the tube. Further, since the separation in this case is not objectionable, we might just as well leave off the glass from the edge

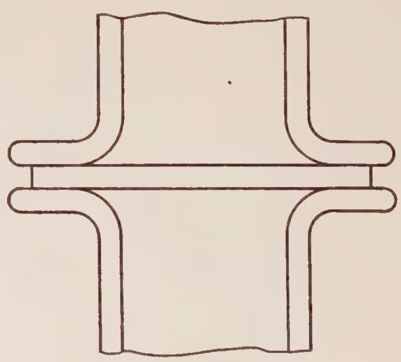


Fig. 9

of the disk and apply glass only to the two faces. This is shown in Fig. 9. This then results in two pieces of glass tubing, one end of each being flared and the two flares melted to opposite faces of a single copper disk. As a matter of fact, such a seal is entirely possible. The final step in the development of the disk

seal is shown in Fig. 10. A round copper wire is passed through a centrally located hole in the disk and is soldered to the disk. Tubing on one face of the disk is almost entirely removed, leaving only a torus of glass in contact with one face. Fig. 11 shows such a disk seal. This type of seal has certain advantages over the ribbon seal. First, the electrical conductor is round and thus of a shape easily obtainable commercially. It is more rigid than a corresponding section of copper ribbon. The disk can easily be punched out on a punch press and requires no filing or machining.

In this seal the stresses are more simple than in the ribbon seal. The copper disk is stretched radially in all directions upon cooling. The glass is subjected to compression only without bending stresses such as occur in the ribbon seal. The disk contracts in thickness by an amount sufficient to compensate for the restricted radial contraction.

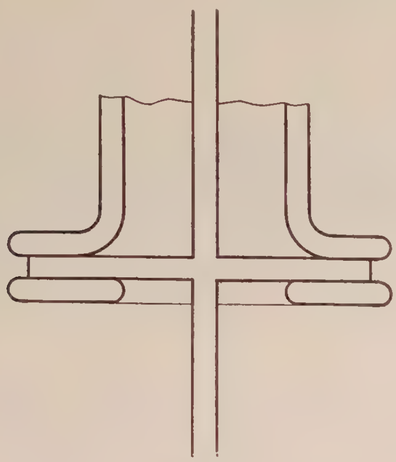


Fig. 10

Care must be taken to prevent glass on one side from running over the edge and making contact with glass on the opposite side of the disk, for if it should make contact, the seal will be broken, because the glass around the edge will not contract as far as the copper disk contracts in thickness.

Fig. 11

As in the ribbon seal, so also in this disk seal, the copper is under tension, though in two dimensions instead of in three. In consequence, when the disk is heated by passage of current through the central conductor, the copper when first expanded reduces the tension stresses so that the corresponding stress in the glass is actually lessened and passes through zero before any possible destructive stresses are applied to the glass by the copper. For example, a certain disk seal, made with a disk 1 3/16 in. diameter (3 cm.) and No. 6 B & S gage copper wire, (0.162 in. diameter — 4.1 mm.) normally carries a current of 90 amperes. Such a seal will carry any current which the copper wire is capable of conducting short of fusing the copper wire. Such a seal will carry 1200 amperes suddenly applied, though a current of 700 amperes will fuse the wire in air if applied for several minutes. As a matter of fact, the disk seal will remain tight even with the copper conductor operating at red heat. Thus this type of seal has the very desirable feature of withstanding heavy overload. It, of course, has the further desirable feature that it has the full conductivity of the given size of copper wire, there being no intermediate portion having a higher resistance.

There seems to be no reason why disk seals of any desired conductivity cannot be made if it is found necessary to make them. 3/8 in. diameter (10 mm.) of copper conductor, is as large as we have so far found it necessary to try out. For exceedingly heavy currents, still another type of seal is available, which will be referred to a little later.

The thickness of the disk is determined by the subsequent use to which the seal is to be put. For example, it is quite possible to seal a disk 1 in. in diameter (25.4 mm.) and 3/32 in. in thickness (2.5 mm.) between two flared glass tubes. However, such a seal once cooled to room temperature will not withstand subsequent heating and cooling. The explanation seems to be that even though the copper is thoroughly annealed when red hot with application of glass yet the subsequent stretching of the copper as it cools off, hardens the copper to an appreciable degree, thus raising the elastic limit and thus increasing the stress which the copper passes through the joint to the glass. Thus in proportioning a seal which is to withstand a great number of repeated cycles of heating and cooling, it is necessary to decrease the thickness of the disk until the maximum stress which the copper can pass to the glass is less than the ultimate strength of the glass. In the case of the 1 in. diameter (25.4 mm.) disk, a convenient thickness is 0.020 in. (0.5 mm.) or 0.030 in. (0.75 mm.).

Glass may be sealed to opposite faces of a copper cent and if carefully annealed, the cent may be made a great circle of a glass sphere.

Theoretical calculations of the relation between thickness and diameter of a disk indicate dimensions of the same order of magnitude as those found by experiment, although here again, as in the case of the ribbon seal, the elastic constants of the glass and copper are not definitely known, nor is the temperature at which the glass may be assumed to solidify a definite quantity.

There are thus, three methods by which copper may be sealed through glass for use as electrical conductors; first, the borax-coated, flattened copper wire; second, the ribbon seal, and third, the disk seal.

The function of the borax in the case of the flattened wire seems to be to provide material next to the copper

which by its low melting point decreases the temperature difference over which the copper is stretched upon cooling. For example, on a certain flattened seal wire with borax the thickness of the flat was 0.0015 in. (0.037 mm.) and without borax it was found necessary to decrease the thickness to 0.0009 in. (0.023 mm.). It is necessary only on the smaller seals where the copper should be as strong mechanically as possible. For ribbon seals and disk seals, borax is not used, the dimensions of the copper being sufficiently large to withstand ordinary handling.

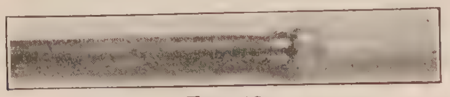


Fig. 12

With the success attending the development of the ribbon and disk seals, further experiments were made to determine the possibility of joining metal tubing to glass tubing. For example, a ½ in. diameter (13 mm.) copper tube was spun outwardly in a flange at one end and the resulting flange was sealed to glass tube in a manner similar to that employed in making disk seals. The over-all diameter of such a seal, however, is of course considerably larger than the diameter of the copper tube. Consequently the experiment shown in

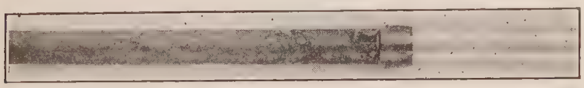


Fig. 13

Fig. 12 was tried and found to be practicable. In this case a copper tube is machined at one end to provide a thin wall of copper. Glass is melted to the outside and joined to a glass tube of suitable size. Here, again, the copper is under tension as the seal cools, yet the adhesion of the glass to the copper is sufficient to stretch the copper as it cools. Further experiments showed that if the glass accidentally ran across the end of the tube, the seal failed at that point because the glass in this case impeded the contraction in thickness of the

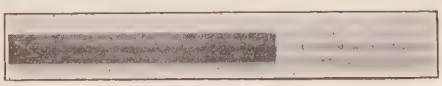


Fig. 14

copper tube. To avoid this difficulty, the expedient used on the ribbon seal was adopted and the edge of the copper tube machined to a knife edge. Then should any glass pass over the edge, failure of the seal would not occur.

Fig. 13 shows a seal of this type in which the copper tube has been reduced to a knife edge at the open end. Here the glass is applied outside of the copper and in this form is known as an external seal. Fig. 14 shows glass tubing applied to the inside of the same sort of copper tubing. This is known as an internal seal. It has been found that there is a difference in the behavior of internal and external seals made with the same dimensions of the copper tube. An internal seal will resist sudden heating much better than an external seal, while an external seal will resist sudden cooling much better than an internal seal. So far, there seems to be no limit to the size of copper tubing which can be joined to glass tubing.

Fig. 15 shows a seal between a 3½ in. diameter (9 cm.) copper tube and a 5 in. (12.8 cm.) diameter glass tube. In this seal the copper tubing is materially reduced in thickness over that portion which comes in contact with the glass.

As in the case of the other forms of seal, the tube seal

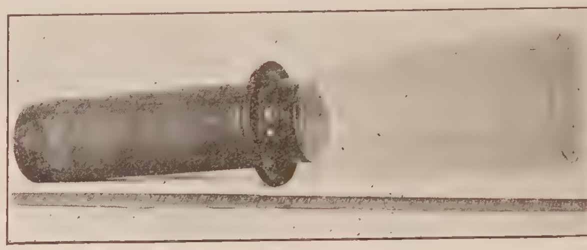


Fig. 15

is not restricted to either copper or lead glass. Fig. 16 shows a seal made between lead glass having a coefficient of expansion of $9 \times 10^{-6}$, Pyrex glass with a coefficient of expansion of $3 \times 10^{-6}$, and copper with a coefficient of expansion of $17 \times 10^{-6}$. In this case a copper tube is sealed to a Pyrex glass tube at one end and to a lead glass tube at the opposite end.

If it should ever be necessary to seal exceedingly heavy copper conductors through glass, such, for example, as a copper shaft 2 in. or 3 in. in diameter, the easy way to accomplish this would be to select a copper tube slightly flared at one end, which would slide easily over the copper shaft. To the flared end of the copper tube

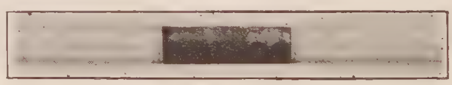


Fig. 16

the glass could be sealed and then after the seal was made, the copper tube could be brazed or welded to the copper shaft.

In conclusion, there does not seem to be any limit to the size of the seals which can be made between metal and glass, so long as the parts are properly proportioned. The practical limit is reached in the laboratory, due to the weight of the parts to be handled and the necessity for keeping the parts in the proper relative relation. This, however, is purely a matter of design of mechanical means for so supporting the weights that they may be moved into proper relative positions.

It has thus been shown that where the parts are properly proportioned the difference in coefficients of expansion of the metal and the glass may be made of no effect upon the strength of the resulting seals.

# Proximity Effect in Wires and Thin Tubes

BY H. B. DWIGHT
Member, A. I. E. E.
Canadian Westinghouse, Ltd., Hamilton, Ont.

***Review of the Subject.**—Formulas are given, with examples, for the following new problems in proximity effect resistance ratio: Thin Tube and Infinitesimal Wire; Two Thin Tubes in Return Circuit; Two Thin Tubes in Parallel; Insulated Cable Sheaths in Single-Phase Circuit; Cable Sheaths in Three-Phase Circuit, Flat Spacing; Finite Wire and Infinitesimal Wire; Two Wires in Parallel; Three-Phase Circuit, Triangular Spacing; Three-Phase Circuit, Flat Spacing.*

*Reduction formulas for Bessel functions, suitable for skin effect problems, are tabulated, and a table of values of the first five orders, for use in drawing curves, is given.*

* * *

THE calculation of the alternating-current resistance ratio due to skin effect or proximity effect, has been worked out for a number of shapes and combinations of conductors. The case of an isolated wire was solved by Clerk Maxwell in 1873, (Reference I). This solution is usually expressed in terms of Bessel functions of the first kind. In 1886, Lord Rayleigh gave the calculation for skin effect in an infinite plane conductor, (Reference 2), and in 1909 Dr. A. Russell published a calculation for a concentric main, that is, a return wire inside of a tube (Reference 3).

The effect on the resistance, caused by current distortion in conductors in armature slots, was treated by A. B. Field, 1905, (Reference 4), R. E. Gilman, 1920, (Reference 5) and W. V. Lyon, 1922, (Reference 6).

In 1915, A. E. Kennelly, F. A. Laws and P. H. Pierce published some very precisely measured curves of various shapes and combinations of conductors taken up to 5000 cycles, (Reference 7). These were very valuable, for in 1915 the only calculation which was in a form to be applied to a finite conductor and checked by test was the calculation for an isolated wire, which they checked exactly. Several of the other test

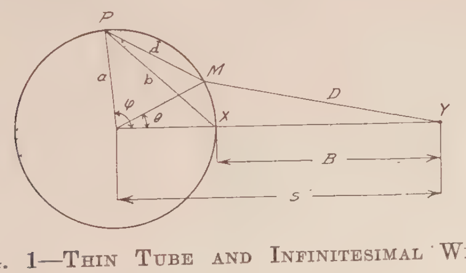



FIG. 1—THIN TUBE AND INFINITESIMAL WIRE

curves have since been checked by calculations, and the curves have been of undoubted help to those deriving the new formulas. Similar test curves up to 100,000 cycles were published in 1916 by A. E. Kennelly and H. A. Affel, (Reference 8).

The proximity effect resistance ratio in a return circuit of two thin straps close together was published by the writer in 1916, (Reference 9).

In 1918, (Reference 10), calculations were published by the writer for skin effect in an isolated tube, and in an isolated thin strap, the latter at low frequency. (See also Reference 11 in which the exact skin effect ratio of a tube is given in terms of Bessel functions of the first and second kinds). In the 1918 paper, the "principle of similitude" was enunciated by the writer, that for a certain shape of cross section of circuit the resistance ratio is constant for a given value of $f/R$, thus correlating tests made at radio frequencies with those made for electric furnace work, etc. A proof of this principle was published by J. Slepian (Reference 12).

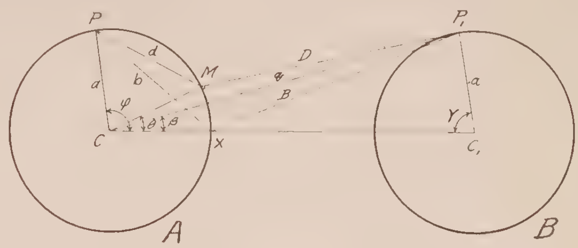



FIG. 2—TWO THIN TUBES IN RETURN CIRCUIT

The proximity effect in a return circuit of two wires was calculated for low frequencies in 1920 by H. L. Curtis (Reference 13). A complete solution was published by J. R. Carson in 1921, (Reference 14), and an alternative solution is given in this paper, (Formula VII).

The skin effect of a cable with steel armor wires and sea water return was calculated by J. R. Carson and J. J. Gilbert in 1921, (Reference 15).

The proximity effect of two thin tubes at low frequencies was given by the writer in 1922 (Reference 16). This result is checked and extended to high frequencies in this paper.

In 1922 a valuable mathematical paper on skin effect was published by Chas. Manneback (Reference 17), in which he describes a new method of attacking a skin effect problem. As with other new methods of solving skin effect problems mentioned in the above summary, this method is first used to obtain the standard formula for an isolated wire. The method is then applied to the case of the proximity effect of a finite wire and an infinitesimal wire, and an expression for the current density at any point of the section of the finite wire is obtained. No expression for the resistance ratio $R'/R$ was obtained, and at first sight, the integration of the resistance losses over the section of the finite wire

*Presented at the Annual Convention of the A. I. E. E., Swampscott, Mass., June 25-29, 1923.*

would appear to involve very complicated integrals in Bessel functions. The method the writer has adopted to overcome this apparent limitation of Manneback's method is to make use of a device involving Poynting's Theorem, given by J. R. Carson in Reference 14, equation (**18**).

The writer has used the above general method to obtain new formulas for ten cases of proximity effect resistance ratio (see Part II). The formulas are good for high frequencies as well as low. Except in the case of a return circuit of two wires, and the low-frequency range of two thin tubes, the problems are new and the values of the resistance ratio were previously not obtainable. The problems are of practical value in electric furnace work, underground cable work and radio work, as indicated in the examples. See also the examples in Reference 16.

## I. Thin Tube and Infinitesimal Wire

Let $X\,M\,P$ be an extremely thin tube of radius $a$ and thickness $t$, and let $Y$ be a very small return conductor. The calculation applies to the case in which the ratio of the thickness of the tube to its diameter is very small, and so the change in current density from the inner to the outer surface is inappreciable compared with the changes in current density in different parts of the tube due to the proximity of the return conductor. The return current is assumed concentrated at the point $Y$.

Let the current density at $M$ be $i_{(\theta)}$. Then the resistance drop at $M$ is $i_{(\theta)}\,\sigma$ where $\sigma$ is the specific resistance of the conductor, absolute units being used. Similarly, if $i_0$ is the current density at $X$, the resistance drop at $X$ is $i_0\,\sigma$.

The difference between the inductance drops at $X$ and $M$ due to flux caused by the current $I_1$ in the return conductor $Y$ is given by the well-known inductance formula and is

$$j\,\omega\,2\,I_1 \operatorname{logh} \frac{D}{B} \text{ volts per cm.}$$

Let the current density at $P$ be $i_{(\varphi)}$ and the element of area of section at $P$ be $a\,t\,d\,\varphi$. The difference between the inductance drops at $X$ and $M$ due to flux caused by the current $i_{(\varphi)}\,a\,t\,d\,\varphi$ at $P$ is

$$j\,\omega\,2\left(\operatorname{logh}\frac{d}{b}\right) i_{(\varphi)}\,a\,t\,d\,\varphi$$

This may be integrated around the tube and the difference between the inductance drops at $X$ and $M$ due to current in the tube is

$$j\,\omega\,2\int_{\varphi=0}^{\varphi=2\pi}\left(\operatorname{logh}\frac{d}{b}\right) i_{(\varphi)}\,a\,t\,d\,\varphi$$

Adding the resistance and inductance drops

$$i_{(\theta)} = i_0 + j\,\frac{2\,\omega}{\sigma}\,I_1 \operatorname{logh}\frac{D}{B} + j\,\frac{2\,\omega}{\sigma}\int_{\varphi=0}^{\varphi=2\pi}\left(\operatorname{logh}\frac{d}{b}\right) i_{(\varphi)}\,a\,t\,d\,\varphi \qquad (1)$$

This is the same as Manneback's equation (**5**) Reference 17.

Let $\qquad l^2 = \dfrac{\omega\,2\,\pi\,a\,t}{\sigma}$ as in equation (**9**)

Reference 16.

Then $j\,\dfrac{2\,\omega}{\sigma} = j\,\dfrac{l^2}{\pi\,a\,t}$

$$\begin{aligned} B &= X\,Y = s - a \\ d^2 &= M\,P^2 = a^2 + a^2 - 2\,a^2 \cos(\theta - \varphi) \\ b^2 &= X\,P^2 = a^2 + a^2 - 2\,a^2 \cos\varphi \\ D^2 &\doteq Y\,M^2 = s^2 + a^2 - 2\,a\,s \cos\theta \end{aligned}$$

The series expansions given by H. L. Curtis, Note 1, Reference 13, where their derivation may be found, must now be used.

$$\operatorname{logh} d/a = -\left\{\cos(\varphi - \theta) + 1/2 \cos 2(\varphi - \theta) + \ldots + 1/n \cos n(\varphi - \theta) + \ldots\right\} \qquad (2)$$

$$\operatorname{logh} b/a = -\left\{\cos\varphi + 1/2\cos 2\,\varphi + \ldots + 1/n \cos n\,\varphi + \ldots\right\} \qquad (3)$$

$$\operatorname{logh} D/s = -\left\{a/s \cos\theta + \frac{a^2}{2\,s^2}\cos 2\,\theta + \ldots + \frac{a^n}{n\,s^n}\cos n\,\theta + \ldots\right\} \qquad (4)$$

First, let the effect of the return current be neglected, and put $i_{(\varphi)} = i_0$

$$i_{(\theta)} = i_0 + \frac{j\,l^2}{\pi\,a\,t}\int_{\varphi=0}^{\varphi=2\pi}(\operatorname{logh} d/a - \operatorname{logh} b/a)\, i_0\,a\,t\,d\,\varphi$$

Using the series expansions, all the terms of the integrals are zero, and $i_{(\theta)} = i_0$ when the effect of the return current is neglected. This result, of course, is known from the conditions of the problem.

Now, for the present, neglect the effect of $i_0$ and find a value of $i_{(\theta)}$ which will balance the effect of the return conductor.

$$i_{(\theta)} = \frac{j\,l^2}{\pi\,a\,t}\,I_1\left(\operatorname{logh} D/s + \operatorname{logh}\frac{s}{s-a}\right) + \frac{j\,l^2}{\pi\,a\,t}\int_{\varphi=0}^{\varphi=2\pi}(\operatorname{logh} d/b)\, i_{(\varphi)}\,a\,t\,d\,\varphi$$

The $n$th term of logh $D/s$ is $-\dfrac{a^n}{n\,s^n}\cos n\,\theta$

Find a solution $i_{n(\theta)}$ of the equation

$$i_{n(\theta)} = -\frac{j\,l^2}{\pi\,a\,t}\,I_1/n\,\frac{a^n}{s^n}\cos n\,\theta + \frac{j\,l^2}{\pi\,a\,t}\int_{\varphi=0}^{\varphi=2\pi}(\operatorname{logh} d/b)\, i_{n(\varphi)}\,a\,t\,d\,\varphi \qquad (5)$$

Let $\quad i_{n(\theta)}^{(1)} = -\dfrac{j\,l^2}{n}\,\dfrac{I_1}{\pi\,a\,t}\,\dfrac{a^n}{s^n}\cos n\,\theta \qquad (6)$

$$i_{n(\theta)}^{(2)} = i_{n(\theta)}^{(1)} + \frac{j\,l^2}{\pi\,a\,t}\int_{\varphi=0}^{\varphi=2\pi}(\operatorname{logh} d/a - \operatorname{logh} b/a)\, i_{n(\varphi)}^{(1)}\,a\,t\,d\,\varphi \qquad (7)$$

$$i_{n(\theta)}{}^{(2)} = i_{n(\theta)}{}^{(1)} + \left(\frac{j\,l^2}{\pi\,a\,t}\right)^2 I_1/n\,\frac{a^n}{s^n}$$

$$\int_{\varphi=0}^{\varphi=2\pi} \cos n\,\varphi \left[\sum_{k=1}^{k=\infty} \frac{\cos k\,(\varphi-\theta)}{k} - \sum_{k=1}^{k=\infty}\frac{\cos k\,\varphi}{k}\right] a\,t\,d\,\varphi$$

Now $\cos A \cos B = 1/2 \cos(A+B) + 1/2\cos(A-B)$ The integrals of all the terms are zero except when $k = n$.

$$i_{n(\theta)}{}^{(2)} = i_{n(\theta)}{}^{(1)} + \left(\frac{j\,l^2}{\pi\,a\,t}\right)^2 I_1/n\,\frac{a^n}{s^n}$$

$$\int_{\varphi=0}^{\varphi=2\pi}\left[\frac{\cos n\,\theta}{2\,n} - \frac{1}{2\,n}\right] a\,t\,d\,\varphi$$

$$i_{n(\theta)}{}^{(2)} = i_{n(\theta)}{}^{(1)} + \left(\frac{j\,l^2}{\pi\,a\,t}\right)^2 I_1/n\,\frac{a^n}{s^n}\left(\frac{\pi\cos n\,\theta}{n} - \pi/n\right) a\,t$$

$$i_{n(\theta)}{}^{(2)} = i_{n(\theta)}{}^{(1)} - \frac{j\,l^2}{n}\,i_{n(\theta)}{}^{(1)} - \left(\frac{j\,l^2}{n}\right)^2 \frac{I_1}{\pi\,a\,t}\,a^n/s^n \qquad (8)$$

Put $$i_{n(\theta)}{}^{(3)} = i_{n(\theta)}{}^{(1)} + \frac{j\,l^2}{\pi\,a\,t}\int_{\varphi=0}^{\varphi=2\pi}(\text{logh}\, d/a - \text{logh}\, b/a)\, i_{n(\varphi)}{}^{(2)}\, a\,t\,d\,\varphi$$

$$= i_{n(\theta)}{}^{(2)} - \frac{j\,l^2}{n}\,\frac{j\,l^2}{\pi\,a\,t}\int_{\varphi=0}^{\varphi=2\pi}(\text{logh}\, d/a - \text{logh}\, b/a)\, i_{n(\varphi)}{}^{(1)}\, a\,t\,d\,\varphi$$

$$- \left(\frac{j\,l^2}{n}\right)^2 \frac{j\,l^2}{\pi\,a\,t}\int_{\varphi=0}^{\varphi=2\pi}(\text{logh}\, d/a - \text{logh}\, b/a)\,\frac{I_1}{\pi\,a\,t}\,\frac{a^n}{s^n}\,a\,t\,d\,\varphi$$

from (7). The last integral is zero.

$$i_{n(\theta)}{}^{(3)} = i_{n(\theta)}{}^{(2)} + \left(\frac{j\,l^2}{n}\right)^2 i_{n(\theta)}{}^{(1)} + \left(\frac{j\,l^2}{n}\right)^3 \frac{I_1}{\pi\,a\,t}\,\frac{a^n}{s^n} \text{ as in } \qquad (8)$$

$$= i_{n(\theta)}{}^{(1)}\left[1 - \frac{j\,l^2}{n} + \left(\frac{j\,l^2}{n}\right)^2\right] - \left(\frac{j\,l^2}{n}\right)^2 \frac{I_1}{\pi\,a\,t}\,a^n/s^n\left[1 - \frac{j\,l^2}{n}\right] \qquad (9)$$

Similarly,

$$i_{n(\theta)}{}^{(4)} = i_{n(\theta)}{}^{(3)} - \left(\frac{j\,l^2}{n}\right)^3 i_{n(\theta)}{}^{(1)} - \left(\frac{j\,l^2}{n}\right)^4 \frac{I_1}{\pi\,a\,t}\,a^n/s^n$$

$$= i_{n(\theta)}{}^{(1)}\left[1 - \frac{j\,l^2}{n} + \left(\frac{j\,l^2}{n}\right)^2 - \left(\frac{j\,l^2}{n}\right)^3\right] - \left(\frac{j\,l^2}{n}\right)^2 \frac{I_1}{\pi\,a\,t}\,a^n/s^n\left[1 - \frac{j\,l^2}{n} + \left(\frac{j\,l^2}{n}\right)^2\right] \qquad (10)$$

If this process is continued indefinitely, the value of $i_{n(\theta)}$ is given by convergent infinite series, provided the values of $l$ and $n$ are such as to make the series convergent. Since $n$ is equal to 1 or greater, the series give the value of $i_{n(\theta)}$ for $l$ less than 1. The sum of the infinite series is

$$\frac{1}{1 + \frac{j\,l^2}{n}}$$

Thus $$i_{n(\theta)} = -\frac{I_1}{\pi\,a\,t}\,\frac{a^n}{n\,s^n}\,\frac{j\,l^2}{1+\frac{j\,l^2}{n}}\cos n\,\theta - \frac{I_1}{\pi\,a\,t}\,\frac{j\,l^2}{n}\,\frac{a^n}{n\,s^n}\,\frac{j\,l^2}{1+\frac{j\,l^2}{n}} \qquad (11)$$

and the value of $i_{(\theta)}$ which will balance the effect of the return conductor is

$$i_{(\theta)} = \frac{j\,l^2 I_1}{\pi\,a\,t}\sum_{n=1}^{n=\infty}\frac{a^n}{n\,s^n} - \frac{j\,l^2 I_1}{\pi\,a\,t}\sum_{n=1}^{n=\infty}\frac{a^n}{n\,s^n}\,\frac{j\,l^2}{(n+j\,l^2)} - \frac{I_1}{\pi\,a\,t}\sum_{n=1}^{n=\infty}\frac{a^n}{n\,s^n}\,\frac{j\,l^2}{1+\frac{j\,l^2}{n}}\cos n\,\theta$$

$$i_{(\theta)} = \frac{j\,l^2 I_1}{\pi\,a\,t}\sum_{n=1}^{n=\infty}\frac{a^n}{n\,s^n}\,\frac{1}{1+\frac{j\,l^2}{n}}(1-\cos n\,\theta) \qquad (12)$$

To this must be added the quantity $i_0$ to obtain the total value of $i_{(\theta)}$

$$i_{(\theta)} = i_0 + \frac{I_1}{2\,\pi\,a\,t}\sum_{n=1}^{n=\infty} a^n/s^n\,\frac{2\,j\,l^2}{(n+j\,l^2)}(1-\cos n\,\theta)$$

$$\text{The total current} = I = -I_1 = \int_{\theta=0}^{\theta=2\pi} i_{(\theta)}\, a\, t\, d\,\theta$$

$$I = 2\,\pi\, a\, t\, i_0 - I \sum_{n=1}^{n=\infty} a^n/s^n \frac{2\,j\,l^2}{(n+j\,l^2)}$$

$$i_0 = \frac{I}{2\,\pi\, a\, t}\left[1 + \sum_{n=1}^{n=\infty} a^n/s^n \frac{2\,j\,l^2}{(n+j\,l^2)}\right] \qquad (13)$$

$$i_{(\theta)} = \frac{I}{2\,\pi\, a\, t}\left[1 + \sum_{n=1}^{n=\infty} a^n/s^n \frac{2\,j\,l^2}{(n+j\,l^2)} \cos n\,\theta\right] \qquad (14)$$

This value of $i_{(\theta)}$ should now be checked by writing $i_{(\varphi)}$ in accordance with it and substituting in the original equation (1).

$i_0$ is given by (13) and $i_{(\varphi)}$ by (14), changing $\theta$ to $\varphi$.

$$\text{logh } D/B = \sum_{n=1}^{n=\infty} \frac{a^n}{n\,s^n}(1 - \cos n\,\theta)$$

$$\text{logh } d/b = \sum_{k=1}^{k=\infty}\left[\frac{\cos k\,\varphi}{k} - \frac{\cos k\,(\varphi - \theta)}{k}\right]$$

Substituting all these in (1) and carrying out the integration, we obtain equation (14).

This furnishes a check on equation (14) and further shows that it applies for all frequencies, that is, for all values of $l$. While the expression was derived by means of series which were convergent for $l$ less than 1, the expression (14) itself is a convergent series for all values of $l$, that is, for all frequencies, so long as $a/s$ is less than 1, and it has been shown to satisfy the fundamental equations of the problem, irrespective of the value of $l$.

It is now desired to find an expression for $R'/R$.

$$R = \frac{\sigma}{2\,\pi\, a\, t}$$

$$R' = 1/I^2 \int_{\theta=0}^{\theta=2\pi} i_{(\theta)}\, a\, t\, d\,\theta\; \hat{i}_{(\theta)}\, a\, t\, d\,\theta \frac{\sigma}{a\, t\, d\,\theta}$$

where $\hat{i}_{(\theta)}$ is the conjugate of $i_{(\theta)}$, that is, it is the same except that $j$ is replaced by $-j$. The integration of the product of the two series is very similar to that used in deriving (8), all the terms being zero except when the coefficients taken from the two series are alike.

$$R'/R = \frac{2\,\pi\, a\, t}{I^2} \frac{I^2\, a\, t}{(2\,\pi\, a\, t)^2}\left[2\,\pi + \sum_{n=1}^{n=\infty} \frac{\pi\, a^{2n}}{s^{2n}} \frac{2\,j\,l^2}{(n+j\,l^2)} \frac{(-2\,j\,l^2)}{(n-j\,l^2)}\right]$$

$$R'/R = 1 + \sum_{n=1}^{n=\infty} \frac{a^{2n}}{s^{2n}} \frac{2\,l^4}{(l^4+n^2)}$$

as in Formula I, Part II.

## II. Two Thin Tubes in Return Circuit

For the case of two thin tubes, equation (3′) of Maneback's paper was not used. Instead, an element of current, $i_{(\gamma)}\, a\, t\, d\,\gamma$ was assumed at $P_1$, the current density $i_{(\gamma)}$ being considered to be constant at first. The following expansions from H. L. Curtis' paper, Reference 13, are required:

$$\text{logh } B/q = -\sum_{n=1}^{n=\infty} \frac{a^n}{n\,q^n}\cos n\,\beta \qquad (15)$$

$$\text{logh } D/q = -\sum_{n=1}^{n=\infty} \frac{a^n}{n\,q^n}\cos n\,(\beta - \theta) \qquad (16)$$

$$\text{logh } q/s = -\sum_{n=1}^{n=\infty} \frac{a^n}{n\,s^n}\cos n\,\gamma \qquad (17)$$

$$\frac{\cos n\,\beta}{q^n} = 1/s^n\left[1 + \sum_{k=1}^{k=\infty} \frac{\underline{|n+k-1}}{\underline{|n-1}\,\underline{|k}} \frac{a^k}{s^k}\cos k\,\gamma\right] \qquad (18)$$

$$\frac{\sin n\,\beta}{q^n} = 1/s^n \sum_{k=1}^{k=\infty} \frac{\underline{|n+k-1}}{\underline{|n-1}\,\underline{|k}} \frac{a^k}{s^k}\sin k\,\gamma \qquad (19)$$

The same process for finding $i_{(\theta)}$ is now gone through as for a thin tube and an infinitesimal wire, and when $i_{(\gamma)}$ is constant the same result is obtained, namely eq. (14). This is to be expected, for a round tube or wire with uniform current density has the same external effect as if the current were concentrated at its center.

Now assume that there is the same current density in tube $B$ as has just been calculated for tube $A$, and the resulting current density in tube $A$ can be found. This again can be assumed for tube $B$. The process gives a symmetrical sequence of expressions, as given in Formula II, Part II. The expression for $R'/R$ is obtained by direct integration, as previously described.

## III. Two Thin Tubes in Parallel

This case is calculated in the same way as the preceding, except that $I$ is used instead of $-I$ for the second conductor, with the result given in Formula III.

## IV. Insulated Cable Sheaths in Single-Phase Circuit

The assumptions for this problem are given under Formula IV, Part II. The calculation is similar to that of Formula I, the total current in the sheath being zero.

## V. Cable Sheaths in Three-phase Circuit, Flat Spacing

The current is $I$ in cable $A$,

$$I e^{j\frac{2\pi}{3}} = I\left(\cos\frac{2\pi}{3} + j\sin\frac{2\pi}{3}\right)$$

$$= I\left(-1/2 + j\frac{\sqrt{3}}{2}\right) \text{ in cable } B, \text{ and}$$

$$I e^{j\frac{4\pi}{3}} = I\left(\cos\frac{4\pi}{3} + j\sin\frac{4\pi}{3}\right)$$

$$= I\left(-1/2 - j\frac{\sqrt{3}}{2}\right) \text{ in cable } C.$$

## VI. Finite Wire and Infinitesimal Wire

The formula for $i_{(r\theta)}$ is derived in Mr. Manneback's paper, equations (14) and (19). It is

$$i_{(r\theta)} = \frac{I}{\pi a^2}\,\frac{j\alpha a}{2}\,\frac{J_0(j\alpha r)}{J_1(j\alpha a)}$$

$$+ \frac{I_1}{\pi a^2}\, j\alpha a \sum_{n=1}^{n=\infty} a^n/s^n \,\frac{J_n(j\alpha r)}{J_{n-1}(j\alpha a)}\cos n\theta \quad (20)$$

where $\alpha^2 = \dfrac{j\,4\pi\omega}{\sigma}$ (21)

In order to derive an expression for $R'/R$, the writer replaced $i_{(r\theta)}$ by $E/\sigma - e_{(r\theta)}/\sigma$ (see note 5 of Manneback's paper) where $E$ is the voltage induced by flux cutting the axis of the wire.

By eq. (10) of J. R. Carson's paper, Reference 14,

$$j\mu\omega H_\theta = \frac{\partial}{\partial r}\, e_{(r\theta)} \quad (22)$$

where $\mu$ is the permeability, assumed $= 1$ for this problem, and $H_\theta$ is the tangential component of the magnetic force.

At the surface,

$$H_{(a\theta)} = \alpha/\omega\,\frac{I\sigma}{\pi a^2}\left[-\frac{j\alpha a}{2}\,\frac{J_0'(j\alpha a)}{J_1(j\alpha a)}\right.$$

$$\left. + j\alpha a \sum_{n=1}^{n=\infty}\frac{a_n}{s_n}\,\frac{J'_n(j\alpha a)}{J_{n-1}(j\alpha a)}\cos n\theta\right] \quad (23)$$

By eq. (18) of Carson's paper, the true energy transferred to or from one cm. of wire through its surface, according to Poynting's theory, is

$$\hat{I}\, I\, R' = \text{real part of } \frac{a}{4\pi}\int_{\theta=0}^{\theta=2\pi} \hat{e}_{(a\theta)}\, H_{(a\theta)}\, d\theta \quad (24)$$

Since this involves only values at the surface of the wire, the integration is not complicated.

$$e_{(a\theta)} = E - \frac{I\sigma}{\pi a^2}\left[\frac{j\alpha a}{2}\,\frac{J_0(j\alpha a)}{J_1(j\alpha a)}\right.$$

$$\left. - j\alpha a \sum_{n=1}^{n=\infty} a^n/s^n\,\frac{J_n(j\alpha a)}{J_{n-1}(j\alpha a)}\cos n\theta\right] \quad (25)$$

The term involving $E$ in $\hat{I}\, I\, R'$ is the real part of

$$\frac{a}{4\pi}\int_{\theta=0}^{\theta=2\pi} \hat{E}\, H_{(a\theta)}\, d\theta$$

By Carson's paper, (17),

$$4\pi I = \int_{\theta=0}^{\theta=2\pi} H_{(a\theta)}\, a\, d\theta \quad (26)$$

$E$ is a voltage caused by flux generated in the axis by the current $I$ in the finite wire and by the current $-I$ in the return wire. Current densities of the form $A\cos n\theta$ do not produce any voltage in the axis, nor any total current, when integrated around the circle. $E$ is therefore in quadrature with $I$, and there is no real part of $\hat{E}\, I$, nor of

$$\int_{\theta=0}^{\theta=2\pi} \hat{E}\, H_{(a\theta)}\, d\theta$$

We have therefore, as before, the integral from 0 to $2\pi$ of the product of two Fourier series (23) and (25). The terms will be zero except where the coefficients of $\theta$ taken from the two series are alike.

$$\text{Put } j\alpha a = b\, j\sqrt{j} \quad (27)$$

where $b^2 = \dfrac{4\pi a^2\omega}{\sigma}$ (28)

so that $b$ is a real quantity. Omit the imaginary parts of the terms of the product and formula VI is obtained.

## VII. Two Wires in Return Circuit

The procedure is the same as for two thin tubes in return circuit, and the same expansions are required. In the course of the calculation it is required to find the current density $i_{(r\theta)}$ due to current density in the return wire

$$i_{(u\gamma)} = c_k\, J_k(j\alpha u)\cos k\gamma$$

The result, after integrating over the surface of the return wire, that is, from $\gamma = 0$ to $2\pi$ and from $u = 0$ to $a$, is

$$i_{(r\theta)} = \sum_{n=1}^{n=\infty} c_k\, a^{n+k}/s^{n+k}\;\frac{J_n(j\alpha r)}{J_{n-1}(j\alpha a)}\cos n\theta$$

$$\frac{\lfloor n+k-1}{\lfloor n-1\,\lfloor k}\; J_{k+1}(j\alpha a) \quad (29)$$

This is only a partial expression used in the course of the calculation. The total value of $i_{(r\theta)}$ is

$$\frac{I}{\pi a^2}\left[A_0 J_0(j\alpha r) + \sum_{n=1}^{n=\infty} N_n J_n(j\alpha r)\cos n\theta\right] \quad (30)$$

As previously stated, Formula VII is an alternative solution, the problem having been solved in J. R. Carson's paper, Reference 14.

### VIII. Two Wires in Parallel

Since in two wires in parallel, the current crowds to the furthermost part of each wire, it is to be expected that their effect on each other will be less than if the current in one were concentrated at the center. So, also, in a return circuit the currents crowd toward each other and the effect is correspondingly greater. This is illustrated by the three values of $R'/R$ given in the example. A similar result was found in connection with thin tubes, Formulas I, II and III.

### IX. Three-Phase Circuit, Triangular Spacing

In this problem, the time phase angles for three-phase currents given in connection with Formula V, cable sheath in three-phase circuit, must be used, and in addition the direction angle $\pi/6$ must be added to, or subtracted from, the angles $\theta$, $\gamma$ etc. With triangular spacing, the three wires and their currents are symmetrical, and each current can be obtained from the one preceding it in the order $A$, $B$, $C$, by multiplying by $e^{j\frac{2\pi}{3}}$

### X. Three-phase Circuit, Flat Spacing

In this problem, as in $V$, the direction angle is $\pi$, used with the middle conductor.

### XI. Bessel Function Reduction Formulas

The first three or four orders of Bessel Functions of the required value of $b$ are usually required. They can be worked out with less work than the remainder of the problem generally requires.

### XII. Table of Bessel Functions

This table gives the values of Bessel Functions of the first five orders, and their first derivatives, for argument $x\, j \sqrt{j}$, where $x$ is any whole number from 1 to 10. These values are useful for drawing curves of proximity effect. Interpolated values cannot be obtained from this table, but must be separately derived by means of the reduction formulas given in XI, from the values of ber $x$ etc. given in Reference 11.

## Part II

### Formulas for Proximity Effect Resistance Ratio

#### I. ○ · Thin Tube and Infinitesimal Wire

$$l^2 = \frac{2\,\pi\, a\, t\, \omega}{\sigma}$$

$a$ = radius of tube in cm.

$t$ = thickness of tube in cm. ($t$ is assumed very small compared with $a$).

$s$ = axial spacing

$\omega$ = $2\,\pi\, f$

$f$ = frequency in cycles per second

$\sigma$ = specific resistivity in absolute units.

$$R'/R = 1 + \sum_{n=1}^{n=\infty} a^{2n}/s^{2n} \; \frac{2\, l^4}{(l^4 + n^2)}$$

For infinite frequency, $R'/R = \dfrac{s^2 + a^2}{s^2 - a^2}$

The above formula applies when the two conductors form a return circuit, and also when they carry equal currents in parallel, and are remote from other conductors. Example, $s/a = 4$, $l = 1$, $R'/R = 1.0641$.

#### II. ○ ○ Two Thin Tubes in Return Circuit

$$A_n = \frac{2\, a^n}{s^n} \; \frac{(l^4 + j\, l^2\, n)}{(l^4 + n^2)}$$

$$B_n = \frac{1}{2}\, A_n \sum_{k=1}^{k=\infty} \frac{a^k}{s^k}\, A_k \, \frac{\underline{/n + k - 1}}{\underline{/n - 1}\;\underline{/k}}$$

$$C_n = \frac{1}{2} A_n \sum_{k=1}^{k=\infty} \frac{a^k}{s^k}\, B_k \, \frac{\underline{/n + k - 1}}{\underline{/n - 1}\;\underline{/k}}$$

$$D_n = \frac{1}{2} A_n \sum_{k=1}^{k=\infty} \frac{a^k}{s^k}\, C_k \, \frac{\underline{/n + k - 1}}{\underline{/n - 1}\;\underline{/k}}$$

etc.

$N_1 = A_1 + B_1 + C_1 + \ldots$

$N_2 = A_2 + B_2 + C_2 + \ldots$

. . . . . .

$N_n = A_n + B_n + C_n + \ldots$

. . . . . .

$$R'/R = 1 + 1/2\,|N_1|^2 + 1/2\,|N_2|^2 + \ldots + 1/2|N_n|^2 + \ldots$$

$|N_n|^2$ is the square of the absolute value of $N_n$. $\underline{/0} = 1$.

Example, $s/a = 4$, $l = 1$, $R'/R = 1.0685$. The same value was obtained by the low frequency calculation given by the writer in Reference 16.

#### III. ○——○ Two Thin Tubes in Parallel

Let $A_1$, $B_1$, . . . . $A_n$, $B_n$, $C_n$ etc. have the same values as for two thin tubes in return circuit.

$M_1 = A_1 - B_1 + C_1 - D_1 + \ldots$

$M_2 = A_2 - B_2 + C_2 - D_2 + \ldots$

. . . . . .

$M_n = A_n - B_n + C_n - D_n + \ldots$

. . . . .

$$R'/R = 1 + 1/2\,|M_1|^2 + 1/2\,|M_2|^2 + \ldots + 1/2\,|M_n|^2 + \ldots$$

Example, $s/a = 4$, $l = 1$, $R'/R = 1.0600$

#### IV. ⊙ · Insulated Cable Sheaths in Single-Phase Circuit

Sheath replaced by a copper sheath of the same resistance, and mean radius and of thickness $t$, and considered as a thin tube. It is insulated from other sheaths except at one point.

Cable inside sheath replaced by a solid wire of the same resistance, and of radius $a$, and whose current density is considered uniform.

Return cable and its sheath represented by an infinitesimal wire.

$$l^2 = \frac{2\,\pi\,c\,t\,\omega}{\sigma}$$

$c$ = radius of sheath

$$\frac{\text{Resis. loss in sheath}}{\text{Resis. loss in cable at zero freq.}} = \frac{a^2}{c\,t} \sum_{n=1}^{n=\infty} c^{2n}/s^{2n} \frac{l^4}{(l^4 + n^2)}$$

If the sheaths are connected at both ends, the currents and losses are approximately calculated by usual reactance formulas.

## V. Insulated Cable Sheaths in Three-Phase Circuit, Flat Spacing

⊙ · · Outside Conductor

Two cables and their sheaths represented by infinitesimal wires. Axial Spacing = $s$.

$$\frac{\text{Resis. loss in sheath}}{\text{Resis. loss in cable at zero freq.}} = \frac{a^2}{c\,t} \sum_{n=1}^{n=\infty} (1 - 1/2^n + 1/2^{2n})\, c^{2n}/s^{2n} \frac{l^4}{(l^4 + n^2)}$$

· ⊙ · *Middle Conductor*

$$\frac{\text{Resis. loss in sheath}}{\text{Resis. loss in cable at zero freq.}} = \frac{a^2}{c\,t} \sum_{n=1}^{n=\infty} (2 - \cos n\,\pi)\, c^{2n}/s^{2n} \frac{l^4}{(l^4 + n^2)}$$

Example. 2,000,000 c.m. single-conductor cables, 60 cycle.

$c = 2.97$ cm., $t = 0.030$ cm., $s = 10.7$ cm.
$c/s = 0.278$ $\sigma = 2100$ at 75 deg. cent.
$l^2 = 0.1005$

$$\frac{\text{Resis. loss in sheath}}{\text{Resis. loss in cable at zero freq.}}$$

= 2.8 per cent for single-phase circuit.
= 2.1 per cent for three-phase circuit, flat spacing, outside conductor
= 8.4 per cent for three-phase circuit, flat spacing, middle conductor.

## VI. ● · Finite Wire and Infinitesimal Wire

All Bessel functions have argument $b\,j\,\sqrt{j}$

$$= j\,\sqrt{j}\,\sqrt{\frac{4\,\pi\,a^2\,\omega}{\sigma}}$$

$$u_0 + j\,v_0 = \text{ber}\, b + j\, \text{bei}\, b = J_0\,(b\,j\,\sqrt{j})$$

$$u_0' = \frac{d\,u_0}{d\,b} = \text{ber}'\, b$$

$$u_n + j\,v_n = J_n\,(b\,j\,\sqrt{j})$$

$$u_n' = \frac{d\,u_n}{d\,b} \text{ etc.}$$

$$R'/R_0 = 1 + \frac{2\,(u_0'^2 + v_0'^2)}{(u_0\,v_0' - u_0'\,v_0)} \sum_{n=1}^{n=\infty} a^{2n}/s^{2n} \frac{(u_n\,v_n' - u_n'\,v_n)}{(u_{n-1}^2 + v_{n-1}^2)}$$

The above formula applies when the two conductors form a return circuit, and also when they carry equal currents in parallel, and are remote from other conductors. $R_0$ = resistance of isolated conductor. As is well known,

$$R_0/R_{dc} = \frac{b}{2} \frac{(u_0\,v_0' - u_0'\,v_0)}{(u_0'^2 + v_0'^2)}$$

This quantity is tabulated in Scientific Paper No. 169 of the Bureau of Standards, by E. B. Rosa and F. W. Grover, page 226. (Reference 18.)

## VII. ●● Two Wires in Return Circuit

All Bessel functions have argument $b\,j\,\sqrt{j}$

$$= j\,\sqrt{j}\,\sqrt{\frac{4\,\pi\,a^2\,\omega}{\sigma}}$$

$$j\,\sqrt{j} = \frac{-1}{\sqrt{2}} + \frac{j}{\sqrt{2}}$$

$$\underline{/0} = 1$$

$$A_0 = \frac{b\,j\,\sqrt{j}}{2\,J_1}$$

$$A_1 = -\,a/s \frac{b\,j\,\sqrt{j}}{J_0}$$

$$A_2 = -\,a^2/s^2 \frac{b\,j\,\sqrt{j}}{J_1}$$

. . . . . .

$$A_n = -\,a^n/s^n \frac{b\,j\,\sqrt{j}}{J_{n-1}} \qquad n \neq 0$$

$$B_n = \sum_{k=1}^{k=\infty} -\,A_k \frac{a^{n+k}}{s^{n+k}} \frac{\underline{/n+k-1}}{\underline{/n-1}\,\underline{/k}} \frac{J_{k+1}}{J_{n-1}}$$

$$C_n = \sum_{k=1}^{k=\infty} -\,B_k \frac{a^{n+k}}{s^{n+k}} \frac{\underline{/n+k-1}}{\underline{/n-1}\,\underline{/k}} \frac{J_{k+1}}{J_{n-1}}$$

. . . . .

$$N_1 = A_1 + B_1 + C_1 + \ldots\ldots$$
$$N_n = A_n + B_n + C_n + \ldots\ldots$$
etc.

$$R'/R_0 = 1 + \frac{1}{2\,|A_0|^2\,(u_0\,v_0' - u_0'\,v_0)} \sum_{n=1}^{n=\infty} |N_n|^2\,(u_n\,v_n' - u_n'\,v_n)$$

$$R_0/R_{dc} = \frac{2}{b}\,|A_0|^2\,(u_0\,v_0' - u_0'\,v_0)$$

These formulas apply very closely to cables as well as wires.

### VIII. Two Wires in Parallel

Let $A_0$, $A_1$, $B_1$ . . . $A_n$, $B_n$, $C_n$ etc. have the same values as for two wires in return circuit.

$$M_1 = A_1 - B_1 + C_1 - D_1 + \dots$$
$$M_2 = A_2 - B_2 + C_2 - D_2 + \dots$$
$$\dots\dots$$
$$M_n = A_n - B_n + C_n - D_n + \dots$$
$$\dots\dots$$

$$R'/R_0 = 1 + \frac{1}{2\,|A_0|^2\,(u_0 v_0' - u_0' v_0)} \sum_{n=1}^{n=\infty} |M_n|^2 (u_n v_n' - u_n' v_n)$$

Example. $s/a = 4$, $b = 10$

$R'/R_0 = 1.101$ for two wires in parallel.

$= 1.114$ for finite wire and infinitesimal wire.

$= 1.129$ for two wires in return circuit.

The third value agrees with that given by J. R. Carson, Reference 14, Fig. 7.

### IX Three-Phase Circuit, Triangular Spacing

$$A_0 = \frac{b\,j\,\sqrt{j}}{2\,J_1} = \frac{b}{2\,J_1}\left(\frac{-1}{\sqrt{2}} + \frac{j}{\sqrt{2}}\right)$$

$$A_n = a^n/s^n \frac{b\,j\,\sqrt{j}}{J_{n-1}}\left(\cos\frac{2\pi}{3} + j\sin\frac{2\pi}{3}\right) \quad n \neq 0$$

$$F_n = a^n/s^n \frac{b\,j\,\sqrt{j}}{J_{n-1}}\left(\cos\frac{4\pi}{3} + j\sin\frac{4\pi}{3}\right)$$

$$B_n = \sum_{k=1}^{k=\infty} a^{n+k}/s^{n+k}\, J_{k+1}/J_{n-1}\, \frac{\underline{|n+k-1}}{\underline{|n-1}\,\underline{|k}} \left(A_k \cos\frac{k\pi}{3} + F_k\right)\left(\cos\frac{2\pi}{3} + j\sin\frac{2\pi}{3}\right)$$

$$G_n = \sum_{k=1}^{k=\infty} a^{n+k}/s^{n+k}\, J_{k+1}/J_{n-1}\, \frac{\underline{|n+k-1}}{\underline{|n-1}\,\underline{|k}} \left(A_k + F_k \cos\frac{k\pi}{3}\right)\left(\cos\frac{4\pi}{3} + j\sin\frac{4\pi}{3}\right)$$

$$C_n = \sum_{k=1}^{k=\infty} a^{n+k}/s^{n+k}\, J_{k+1}/J_{n-1}\, \frac{\underline{|n+k-1}}{\underline{|n-1}\,\underline{|k}} \left(B_k \cos\frac{k\pi}{3} + G_k\right)\left(\cos\frac{2\pi}{3} + j\sin\frac{2\pi}{3}\right)$$

$$H_n = \sum_{k=1}^{k=\infty} a^{n+k}/s^{n+k}\, J_{k+1}/J_{n-1}\, \frac{\underline{|n+k-1}}{\underline{|n-1}\,\underline{|k}} \left(B_k + G_k \cos\frac{k\pi}{3}\right)\left(\cos\frac{4\pi}{3} + j\sin\frac{4\pi}{3}\right)$$

etc.

$$M_n = A_n + B_n + C_n + \dots$$
$$N_n = F_n + G_n + H_n + \dots$$

$$R'/R_0 = 1 + \frac{1}{2\,\hat{A}_0 A_0 (u_0 v_0' - u_0' v_0)} \sum_{n=1}^{n=\infty} \left\{ \hat{M}_n M_n + \hat{N}_n N_n + (\hat{M}_n N_n + M_n \hat{N}_n)\cos\frac{n\pi}{3} \right\} (u_n v_n' - u_n' v_n)$$

$\hat{A}_0$ is the conjugate of $A_0$, that is, the imaginary part of $\hat{A}_0$ is $(-1)$ times the imaginary part of $A_0$. Example. 500,000 c. m. three-conductor cable, 60 cycle, $s/a = 2.5$, $b = 1.4$, $R'/R_0 = 1.055$.

### X Three-Phase Circuit, Flat Spacing

$$A_0 = \frac{b\,j\,\sqrt{j}}{2\,J_1} = \frac{b}{2\,J_1}\left(\frac{-1}{\sqrt{2}} + \frac{j}{\sqrt{2}}\right)$$

In the following, $n \neq 0$

$$A_{an} = A_{bn}\left[\cos\frac{2\pi}{3} + j\sin\frac{2\pi}{3} + 1/2^n\left(\cos\frac{4\pi}{3} + j\sin\frac{4\pi}{3}\right)\right]$$

$$A_{bn} = \frac{b\,j\,\sqrt{j}}{J_{n-1}}\, a^n/s^n = b/J_{n-1}\, a^n/s^n\left(\frac{-1}{\sqrt{2}} + \frac{j}{\sqrt{2}}\right)$$

$$A_{cn} = A_{bn}\left(\cos\frac{4\pi}{3} + j\sin\frac{4\pi}{3}\right)$$

$$A_{dn} = A_{bn}\left(1/2^n + \cos\frac{2\pi}{3} + j\sin\frac{2\pi}{3}\right)$$

$$B_{an} = \sum_{k=1}^{k=\infty} J_{k+1}/J_{n-1} \frac{\underline{|n+k-1}}{\underline{|n-1}\,\underline{|k}} \left[(A_{bk} + A_{ck}\cos k\pi)\, a^{n+k}/s^{n+k} + A_{dk}\frac{a^{n+k}}{(2\,s)^{n+k}}\right]$$

$$B_{bn} = \sum_{k=1}^{k=\infty} J_{k+1}/J_{n-1} \frac{\underline{|n+k-1}}{\underline{|n-1}\,\underline{|k}}\, A_{ak}\, a^{n+k}/s^{n+k}$$

$$B_{cn} = \sum_{k=1}^{k=\infty} J_{k+1}/J_{n-1} \frac{\underline{|n+k-1}}{\underline{|n-1}\,\underline{|k}}\, A_{dk}\, a^{n+k}/s^{n+k}$$

$$B_{dn} = \sum_{k=1}^{k=\infty} J_{k+1}/J_{n-1} \frac{\underline{|n+k-1}}{\underline{|n-1}\,\underline{|k}} \left[A_{ak}\frac{a^{n+k}}{(2\,s)^{n+k}} + (A_{bk}\cos k\pi + A_{ck})\, a^{n+k}/s^{n+k}\right]$$

$C_{an}$, $C_{bn}$ etc. are obtained from the same formulas as $B_{an}$, $B_{bn}$, etc., respectively, except that $A$ is changed to $B$, and similarly for $D_{an}$, $D_{bn}$, etc., change $B$ to $C$. This process can be continued indefinitely.

*Outside Conductors.*

Let $L_n = A_{an} + B_{an} + C_{an} + \ldots$

$R'/R_0$ of outside wires $= 1$

$$+ \frac{1}{2\,|A_0|^2\,(u_0\, v_0' - u_0'\, v_0)} \sum_{n=1}^{n=\infty} |L_n|^2\,(u_n\, v_n' - u_n'\, v_n)$$

*Middle Conductor.*

$M_n = A_{bn} + B_{bn} + C_{bn} + \ldots$

$N_n = A_{cn} + B_{cn} + C_{cn} + \ldots$

$R'/R_0$ of middle conductor

$$= 1 + \frac{1}{2\,|A_0|^2\,(u_0\, v_0' - u_0'\, v_0)} \sum_{n=1}^{n=\infty} \left\{ \hat{M}_n\, M_n + \hat{N}_n\, N_n + (\hat{M}_n\, N_n + M_n\, \hat{N}_n) \cos n\,\pi \right\} (u_n v'_n - u_n' v_n)$$

Putting the $B$'s and $C$'s $= 0$ is equivalent to assuming two of the conductors to be infinitesimal. Formulas VIII, IX and X apply very closely to cables as well as wires. Example: 2,000,000-c.m. single-conductor cables, flat spacing 60 cycle. Neglect the lead sheaths. $s/a = 5$, $b = 2.7$ for 75 deg. cent., $R'/R_0 = 1.03$ for each outside cable, and 1.13 for the middle cable. Each of these figures is multiplied by $1.22 = R_0/R_{dc}$ in order to obtain $R'/R_{dc}$.

## XI. Bessel Function Reduction Formulas

Special

$$u_0 = \operatorname{ber} x$$

$$v_0 = \operatorname{bei} x$$

$$u_1 = + \frac{1}{\sqrt{2}}\,(u_0' - v_0')$$

$$v_1 = + \frac{1}{\sqrt{2}}\,(u_0' + v_0')$$

$$u_2 = - \frac{\sqrt{2}}{x}\,(u_1 - v_1) - u_0 = \frac{2\,v_0'}{x} - u_0$$

$$v_2 = - \frac{\sqrt{2}}{x}\,(u_1 + v_1) - v_0 = - \frac{2\,u_0'}{x} - v_0$$

$$u_2' = - \frac{1}{\sqrt{2}}\,(u_1 + v_1) - \frac{2\,u_2}{x} = - u_0' - \frac{2\,u_2}{x}$$

$$v_2' = + \frac{1}{\sqrt{2}}\,(u_1 - v_1) - \frac{2\,v_2}{x} = - v_0' - \frac{2\,v_2}{x}$$

General

$$u_{n+1} = - \frac{n\,\sqrt{2}}{x}\,(u_n - v_n) - u_{n-1} \qquad n \neq 0$$

$$v_{n+1} = - \frac{n\,\sqrt{2}}{x}\,(u_n + v_n) - v_{n-1} \qquad n \neq 0$$

$$u_n' = - \frac{1}{\sqrt{2}}\,(u_{n-1} + v_{n-1}) - \frac{n\,u_n}{x} \qquad n \neq 0$$

$$v_n' = + \frac{1}{\sqrt{2}}\,(u_{n-1} - v_{n-1}) - \frac{n\,v_n}{x} \qquad n \neq 0$$

Use these formulas with the table of $u_0 = \operatorname{ber} x$, $u_0' = \operatorname{ber}' x$ etc. in Reference 11.

These formulas are also suitable for Bessel functions of the second kind by changing $u$ to $l$ and $v$ to $m$. Thus $\operatorname{ker} x = l_0$ and $\operatorname{kei} x = m_0$, etc.

TABLE I

BESSEL FUNCTIONS, $u_n + j\,v_n = J_n\,(x\,j\,\sqrt{j})$, $v_n' = \frac{d}{d\,x}\,u_n$

| $x$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | $x$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $u_0 = \operatorname{ber} x$ | +0.984 382 | +0.751 734 | −0.221 38 | −2.563 42 | −6.230 08 | − 8.858 32 | − 3.632 9 | +20.974 0 | +73.935 7 | +138 840 | $u_0 = \operatorname{ber} x$ |
| $v_0 = \operatorname{bei} x$ | +0.249 566 | +0.972 292 | +1.937 59 | +2.292 69 | +0.116 03 | − 7.334 75 | −21.239 4 | −35.016 7 | −24.712 8 | + 56.370 | $v_0 = \operatorname{bei} x$ |
| $u_0' = \operatorname{ber}' x$ | −0 062 446 | −0.493 067 | −1.569 85 | −3.134 65 | −3.845 34 | − 0.293 08 | +12.764 5 | +38.311 3 | +65.600 8 | + 51.195 | $u_0' = \operatorname{ber}' x$ |
| $v_0' = \operatorname{bei}' x$ | +0.497 397 | +0.917 014 | +0.880 48 | −0.491 14 | −4.354 14 | −10.846 22 | −16.041 5 | − 7.660 3 | +36.299 4 | +135.309 | $v_0' = \operatorname{bei}' x$ |
| $u_1$ | −0.395 868 | −0.997 078 | −1.732 64 | −1.869 25 | +0.359 78 | + 7.462 20 | +20.368 9 | +32.506 9 | +20.719 2 | − 59.478 | $u_1$ |
| $v_1$ | +0.307 557 | +0.299 775 | −0.487 45 | −2.563 82 | −5.797 91 | − 7.876 67 | − 2.317 2 | +21.673 5 | +72.054 3 | +131.879 | $v_1$ |
| $u_1'$ | −0.476 664 | −0.720 532 | −0.635 99 | +0.658 74 | +4.251 33 | +10.206 52 | +14.677 5 | + 5.866 4 | −37.108 0 | −132.087 | $u_1'$ |
| $v_1'$ | +0.212 036 | −0.305 845 | −1.364 13 | −2.792 83 | −3.327 80 | + 0 235 45 | +12.780 7 | +36.882 2 | +61.749 0 | + 45.127 | $v_1'$ |
| $u_2$ | +0.010 411 | +0.165 279 | +0.808 37 | +2.317 85 | +4.488 43 | + 5.242 91 | − 0.950 4 | −22.889 0 | −65.869 2 | −111.779 | $u_2$ |
| $v_2$ | −0.124 675 | −0.479 225 | −0.891 02 | −0.725 36 | +1.422 10 | + 7.432 14 | +17.592 4 | +25.438 9 | +10.134 8 | − 66.610 | $v_2$ |
| $u_2'$ | +0.041 623 | +0.327 788 | +1.030 93 | +1 975 73 | +2.049 97 | − 1.454 56 | −12.493 0 | −32.589 1 | −50 963 2 | − 28.840 | $u_2'$ |
| $v_2'$ | −0.248 047 | −0.437 789 | −0.286 47 | +0.853 82 | +3.785 30 | + 8.368 74 | +11.015 1 | + 1.300 6 | −38.551 6 | −121.987 | $v_2'$ |
| $u_3$ | +0.013 788 | +0.085 612 | +0.130 44 | −0.282 63 | −2.094 35 | − 6.430 04 | −12.876 5 | −15.420 4 | + 3.166 6 | + 72.253 | $u_3$ |
| $v_3$ | +0.015 629 | +0.141 210 | +0.565 38 | +1.437 76 | +2.154 41 | + 1.901 46 | − 4.407 2 | −22.575 0 | −54.538 7 | − 81.423 | $v_3$ |
| $u_3'$ | +0.039 433 | +0.093 575 | +0.072 00 | −0.914 09 | −2.922 76 | − 5.747 81 | − 6.249 2 | + 3.979 6 | +38.354 6 | +104.463 | $u_3'$ |
| $v_3'$ | +0.048 634 | +0.239 418 | +0.636 27 | +1.073 55 | +0.695 57 | − 2.498 96 | −11.222 9 | −25.707 4 | −35.563 4 | − 7.513 | $v_3'$ |
| $u_4$ | −0.002 60 | −0.040 97 | −0.193 27 | −0.493 10 | −0.628 67 | + 0.648 3 | + 6.083 5 | +19.094 7 | +38.667 | + 46.579 | $u_4$ |
| $v_4$ | −0.000 13 | −0.008 30 | −0.093 02 | −0.499 85 | −1.727 62 | − 4.230 2 | − 7.116 9 | − 5.288 8 | +14.082 | + 70.500 | $v_4$ |
| $u_4'$ | −0.010 40 | −0.080 56 | −0.234 32 | −0.323 71 | +0.248 34 | + 2.770 0 | + 8.745 2 | +17.319 5 | +19.140 | − 12.148 | $u_4'$ |
| $v_4'$ | −0.000 78 | −0.024 83 | −0.183 52 | −0.716 65 | −1.834 36 | − 3.071 1 | − 1.921 9 | + 7.703 5 | +34.545 | + 80.465 | $v_4'$ |
| $u_5$ | +0.000 20 | +0.006 80 | +0.058 59 | +0.273 08 | +0.851 04 | + 1.830 5 | + 2.209 0 | − 1.821 3 | −18.619 | − 58.722 | $u_5$ |
| $v_5$ | −0.000 18 | −0.004 84 | −0.025 54 | −0.033 53 | +0.211 43 | + 1.475 6 | + 5.242 3 | +12.812 8 | +21.384 | + 15.193 | $v_5$ |
| $u_5'$ | +0.000 95 | +0.017 84 | +0.104 78 | +0.360 76 | +0.815 11 | + 1.007 4 | − 0.847 2 | − 8.623 9 | −26.955 | − 53.427 | $u_5'$ |
| $v_5'$ | −0.000 85 | −0.011 00 | −0.028 32 | +0.046 69 | +0.565 64 | + 2.220 0 | + 5.589 6 | + 9.233 7 | + 5.504 | − 24.511 | $v_5'$ |

## Part III. List of References

For a more complete list of articles on this subject, see the bibliography published in Reference 7.

1. J. Clerk Maxwell, Electricity and Magnetism, Vol. 2, 1873, paragraph 689.

2. Lord Rayleigh, *Phil. Mag.*, 1886, pp. 382, 469.

3. A. Russell, *Phil. Mag.* Vol. 17, 1909, p. 524.

4. A. B. Field, "Eddy Currents in Large Slot-Wound Conductors," Proc. A. I. E. E., July, 1905, p. 659.

5. R. E. Gilman, "Eddy Current Losses in Armature Conductors," Trans. A. I. E. E., 1920, p. 997.

6. W. V. Lyon, "Heat Losses in Stranded Armature Conductors," Jour. A. I. E. E., Jan., 1922, p. 37.

7. A. E. Kennelly, F. A. Laws and P. H. Pierce, "Experimental Researches on Skin Effect in Conductors," Trans. A. I. E. E., 1915, p. 1953.

8. A. E. Kennelly and H. A. Affel, "Skin Effect Resistance Measurements," *Proc.* Inst. of Radio Engineers, May, 1916.

9. H. B. Dwight, "Skin Effect of a Return Circuit of Two Adjacent Strap Conductors," *The Electric Journal*, April, 1916, p. 157.

10. H. B. Dwight, "Skin Effect in Tubular and Flat Conductors," Trans. A. I. E. E., 1918, p. 1379.

11. H. B. Dwight, "A Precise Method of Calculation of Skin Effect in Isolated Tubes," Jour. A. I. E. E., Aug. 1923, p. 827.

12. J. Slepian, Discussion on Reference 10, Trans. A. I. E. E., 1918, p. 1401.

13. H. L. Curtis, Scientific Paper No. 374 of the Bureau of Standards, Washington, D. C., 1920.

14. J. R. Carson, "Wave Propagation over Parallel Wires: The Proximity Effect," *Phil. Mag.*, April, 1921, p. 607.

15. J. R. Carson and J. J. Gilbert, "Transmission Characteristics of the Submarine Cable," *Journal* of the Franklin Institute, Dec., 1921, p. 705.

16. H. B. Dwight, "Skin Effect and Proximity Effect in Tubular Conductors," Journal A. I. E. E., Mar., 1922, p. 203.

17. Chas. Manneback, "An Integral Equation for Skin Effect in Parallel Conductors," *Journal of Math. and Physics*, April, 1922.

18. E. B. Rosa and F. W. Grover, Scientific Paper No. 169 of the Bureau of Standards, Washington, D. C., Table XXII, page 226.

---

# Discussion at Midwinter Convention

### DISCUSSION (CONTINUED*) ON "MEASUREMENT OF TRANSIENTS"

(Terman), New York, N. Y., February 16, 1923

**C. L. Fortescue:** Referring to Mr. Frederick Terman's paper on Measurement of Transients, this question of the Measurement of Transients of transmission lines and in apparatus connected to transmission lines, is becoming of great importance. However, there are surges of several kinds; we may have surges of very high voltage, which last for a very short time, so short that they do not do any damage.

It takes more than the application of a high voltage to puncture insulation. Insulation requires time as well as voltage in order to be injured, so that what we really need in the measurement of these transients, is something which will weigh the effect of the surge or transient, so as to give some measure of its real destructiveness.

The mere recording of the maximum values does not appear to be sufficient and may be quite misleading. We ourselves in the Westinghouse Company are working on this problem of developing a device that will record transients, and we are at the same time considering some device that will also give a measure of the destructiveness of the transients.

I have had occasion to do some work on transients in connection with transformers, the switching transients that occur in the transformers. These transients occur across the terminals of transformers and across portions of the lining after the transformer has been removed from the circuit. They may reach four or five times the normal voltage across those portions of the transformer; but usually they are of such short time, and have such a small amount of energy, that they have little effect on the insulation. This is particularly true in connection with oil transformers.

As I said before, it requires more than a high voltage to injure insulation. It requires also an appreciable amount of energy, or what is the same thing, voltage, plus time.

*Continued from August Journal p. 854.

### SYSTEMS OF SINGLE-PHASE REGENERATION FOR USE WITH SERIES TYPE COMMUTATOR MOTORS*

(Hibbard) New York, N. Y. February, 15, 1923

**J. M. Labberton:** Mr. Hibbard disposes of the first two methods he mentions by saying they are more complicated, which is true, and for this reason they will probably not come into popular favor.

The last two methods, shunt excitation and separate excitation, are described quite in detail but there is one point of the problem upon which he did not touch, that is commutation.

We are all more or less familiar with the commutation characteristics of single-phase commutator motors. The voltage producing the spark at the brush is composed of two components, one in phase with the armature current and the other in phase with torque field voltage or ninety degrees (approximately) out of phase with the torque field flux and is proportional in magnitude to this flux or field strength. This is true whether regenerating or motoring.

An examination of the diagrams shown by Mr. Hibbard will indicate how complicated an arrangement would be necessary to compensate for this resultant voltage at all speeds and loads. Consequently, in order to avoid this complication we must consider these points when the motor is designed.

We must make the field weak—weak enough to minimize the voltage component depending thereon to such a point that its ill effects are not appreciable. And then compensate for the other component by means of the straight series commutating pole as in a d-c. machine. This has been done in a number of cases and is practical.

I think Mr. Hibbard did not mention the fact that in d-c. regeneration, the accomplishment is based upon having the voltage produced by armature rotation greater than the line voltage, consequently causing the power to flow from motor to line. But in single-phase regeneration, this is not necessarily true, as for example in the case of the shunt scheme.

In this scheme, the armature voltage is at approximately 90

*A. I. E. E. Journal, 1923, Vol. XLII, March, p. 223.

degrees relation to the line or transformer voltage. This voltage circuit is closed by the reactor voltage, it forming the hypothenuse of the voltage triangle. The regenerated current must be at approximately 90 degrees to this reactor voltage. Consequently, it is readily seen that any diminution of the rotational or armature voltage results only in diminution of the power factor of the regenerated power and diminution of retarding effort but not a reversal of power as in the case of direct current. This is an advantage.

## A NEW METHOD FOR THE ROUTINE TESTING OF A-C. HIGH-VOLTAGE PAPER-INSULATED CABLE*

(Phelps and Tanzer), New York, N. Y., February 14, 1923

**J. L. R. Hayden:** The great value of Messrs. Phelps and Tanzer's paper is its method of indicating the gradual deterioration of a cable insulation. This makes it possible to determine the approach of a failure sufficiently, so that the cable can be broken down out of service by high-potential test, and repaired before it gives trouble in service.

There is probably a slow deterioration of cable insulation while in operation. It is a serious matter to have a cable fail in service. Therefore cables are sometines given an a-c. high-potential test at regular intervals, so that, if deteriorated, they break down in test rather than in service. But the high test voltage, especially when applied for some time, rapidly deteriorates the cable insulations, so that such periodic high-potential testing may materially reduce the life of the cable, without guarding against a break down in service. The cable may fail under normal voltage, shortly after it was tested, if the deterioration occurring under the high-voltage test has almost reached the failure point, and then is completed to the failure point by the succeeding normal voltage.

The method of testing described by Messrs. Phelps and Tanzer offers the advantage of not deteriorating the cable by exposure to abnormal voltage.

The evidence is continuously becoming more conclusive, that electric failure of solid insulation, especially compound insulation as in a cable, is not a puncture by electric overstress by the voltage, but is of the nature of a gradual deterioration by the combined action of voltage, time and temperature. Therefore a judgment on the progress of the deterioration should be made possible by methods of test showing the internal condition of the insulation. This is the case with d-c. tests, but not with a-c. tests. The alternating current taken by the cable under test is the charge on the metal terminals of the cable as condenser, and does not enter or pass through the insulation thus showing nothing about it. The voltage merely shows why the insulation fails, and then destroys its evidence.

The only feature which has a bearing on the insulation, in the a-c. test, is the power factor, which indicates the losses in the insulation. The power factor therefore is justly considered as an important feature, and low power factor specified. While low power factor is valuable and desirable as meaning low losses and therefore lower temperature, it may be questioned whether for instance, a cable with a somewhat higher power factor, but a power factor which does not vary much with voltage, time, temperature, etc., may not give a better life than a cable in which the power factor greatly varies with voltage, time and temperature.

In the d-c. test, the final value of the current is that which is conducted through the total resistance of the insulation, and depends on the latter. Therefore it has a slow transient current, which is the current that passes a few seconds after the initial rush of condenser charging current has ceased. This continues to decrease gradually for several minutes. It is a current which passes into the insulation, therefore passes through some of the resistance, and forms internal electric charges within the insulation. It depends on the specific capacities and the resistivities of the different parts of the insulation, and its study should therefore afford information on what goes on inside of the insulation.

**D. W. Roper:** According to the textbooks, the equation of the curve shown by these authors is as follows:

$$i = \delta_o + \delta_1 \epsilon^{-ct} \qquad (1)$$

That equation, with the half transposition, and taking the logarithms, comes out in this form:

$$\log_\epsilon \frac{1}{i - \delta_o} = c\,t + \log_\epsilon 1/\delta_1 \qquad (2)$$

This equation, you will note, is in the form:

$$y = mx + b,$$

so that it should be a straight line. However, when we take the readings on an underground transmission line and plot them and analyze them, it was discovered by one of my assistants, Mr. Halperin, that instead of getting one straight line, you get two straight lines. The curve found when plotting the points for the second equation seemed to be a straight steep line followed by a curved line in about one minute and finally a less-steep straight line. If you take and work backwards from the first part of the curve and extend it in order to see what the curve would be, if the curve followed the equation for a straight line, then you find that the current goes down to a minimum in about one minute. Or, if you follow the third part curve back to the vertical axis, the initial current reading would be only about one-half of what you actually get; so that apparently the equation as given in the text books needs some revision.

We have endeavored to carry out one of these suggestions of Messrs. Phelps and Tanzer in applying this method of analysis to the modern high-efficiency cables, having a low dielectric loss; but unfortunately, we do not have in these cables, up to the present time, any dielectric loss failures; and it was failures of that particular kind which were discovered in advance and eliminated in Philadelphia.

We have taken quite a few readings and made a number of analyses of tests on these high-efficiency cables, and also on some of the rosin oil cables, which showed very much the same shape of curve; but up to the present time we have not been able to secure practical results from the analysis, but it is interesting to us, at least, to know the peculiar shape of the curve we get upon analysis.

Messrs. Phelps and Tanzer in their paper mentioned that the cables which they tested showed a maximum ratio of 405 to 1, between the initial reading, and the final reading. On some of our 33-kv. cables, we found that the pressure was as high as 150, the current ranging from fifteen milliamperes for the initial reading to 1/10 milli-ampere for the final reading, also, in some of the tests we noticed some interesting differences between the leakage through the cambric insulation and through the impregnated paper insulation.

We have made a number of tests on a 15-mile 33-kv. line, with 19/64 paper around each conductor, and 7/64 belt; and for the test lead between the positive side and the transmission line, we had about 400 ft. of cambric insulated conductor, with about twice the thickness of insulation between the copper and the lead. In making observations on this combination of 400 ft. of cambric cable and the 15-mile line, we find the losses in the paper cable are approximately three-fifths of the total leakage, while there was about 40 per cent of the leakage in the 400 ft. of cambric insulation in the test lead.

**Charles P. Steinmetz:** Messrs. Phelps and Tanzer's paper shows that from the study of the slow cable transient the deterioration of the insulation can be estimated and its failure thereby anticipated. This is rational, as this slow transient depends on the internal conditions of the insulation. It is a true electrical transient, and of special interest by its long duration, often many minutes, while the external transient of charg-

*A I. E. E. Journal, 1923, Vol. XLII, March, p. 247.

ing the condenser terminals over an inductive supply circuit, usually vanishes within a fraction of a second.

This slow cable transient (the so-called soaking in of the charge, etc.) does not exist if the insulation is perfectly homogeneous; but if the insulation consists of $n$ dielectrics of different specific capacities and resistivities, a slow transient of $(n - 1)$ terms appears.

To illustrate the nature of this transient, let us consider a cable as condenser, in which the dielectric consists of layers of two materials of different specific capacities and different resistivities (paper and rosin oil for instance).

The voltage impressed upon the condenser produces an electrostatic flux between the condenser terminals. A line of electrostatic flux must either return into itself, or terminate in an electrostatic charge. At the first moment of the impressed voltage there can be no internal charges in the dielectric, since there was no time to conduct them through the high resistance of the dielectric. Thus in the first moment, the electrostatic flux density is the same in both dielectrics, and the voltage is distributed between the two dielectrics by their specific capacity, that is, the voltage gradients in the two dielectrics are inversely proportional to the specific capacities.

Due to the finite (though extremely low) conductivity of the dielectric, a current is conducted, or leaks, through the dielectric, and the current density of this current in the two dielectrics is proportional to their respective conductivities, and to their voltage gradients, which latter in the initial moment of the phenomenon depend on the specific capacities. Unless then the resistivities of the two dielectrics happen to be exactly proportional to their specific capacities, the current densities in the two component dielectrics must be different. This means that at every boundary between the two dielectrics a change of current density occurs, and more current flows towards the boundary from the one side, than leaves it on the other side, and consequently, an electrostatic charge builds up at the boundary between the two dielectrics, due to the difference between the two current densities on the two sides of the boundary. This electrostatic charge lowers the voltage gradient and thus the current density in the dielectric of higher current density, and raises it in the dielectric of lower current density, until the current densities in both component dielectrics have become equal and any further building up of internal charge ceases.

The final condition thus is that of uniform current density in both component dielectrics, so that the voltage gradients are proportional to the respective resistivities of the two dielectrics.

Thus in a condenser with a compound dielectric, like a cable, after initial electrification by the rapid external charging transient, an internal voltage adjustment occurs, from the initial voltage distribution corresponding to the specific capacities, to the final voltage distribution corresponding to the respective resistivities of the two dielectrics, with a change from uniform electrostatic flux density and non-uniform current density, to uniform current density and ununiform flux densities terminating at internal electrostatic charges at all the boundaries between the two dielectrics. As the internal static charges have to be conducted through the high resistance of the dielectric, this occurs by a very slow transient, of a duration usually many thousand times greater than the external charging transient.

In the final condition, the stored energy of the condenser is greater than in its initial condition, and its capacity therefore higher.

It can be shown that of the energy of this slow internal transient, half is converted into heat in the resistance of the dielectric, the other half stored as electrostatic energy of the internal charges which after discharge partly appears at the terminals as "residual charge."

Numerous other interesting conclusions follow, for instance that the $i^2 r$ loss in the cable dielectric with alternating current may be many times greater than with direct current, and this additional $i^2 r$ loss is independent of the frequency. The difference between the effective resistance of a cable, measured with alternating current, and the d-c. resistance, is not all dielectric hysteresis, but partly at least true resistance, etc.

As seen, this slow transient gives some information on the individual component dielectrics of such a compound structure as a cable, and in view of its importance in estimating cable deterioration, it may be of interest to give in a later paper the equations of it and thus its relation to the resistivities, capacities, etc. of the different component dielectrics.

**G. B. Shanklin:** Messrs. Phelps and Tanzer have developed a method of test based on sound principles with which it is possible to discover cable faults during their incipient stage, thereby filling a long felt and urgent need in underground transmission. They claim only that this method of test has worked out successfully on comparatively low-voltage lines (6000 volts) of the old rosin-oil type cable and offer no predictions as to its future usefulness on lines of other and higher voltages.

Considering the principles upon which their method is based, there is no reason why it should not be just as successful on longer, higher-voltage lines of the new type cable. It is a question of obtaining data to prove this point and such work, I understand, is now under way.

The leakage current through a fault during its incipient stage is extremely small, even smaller than the leakage through the rest of the total cable length. Its detection is, therefore, very difficult and the success Messrs. Phelps and Tanzer have had can be attributed to certain factors in their test method:

1st. The use of d-c. voltage, thereby eliminating charging current which would be so high in comparison with leakage current as to completely obscure the results.

2nd. The use of *high* d-c. voltage, which has a tendency to search out and penetrate weak spots, forcing more current through in proportion to leakage current over rest of line. High d-c. voltage also brings the total current within readable values, eliminating the possibility of errors introduced by stray currents, etc. In view of this the curves should be taken at the highest voltage compatible with safety from damage to the sound portion of the line.

3rd. The opportunity of comparing the current vs. time curves of the individual conductors. Single-conductor cable does not offer this opportunity, but perhaps a comparison of the curves taken on cables of the same circuit in adjacent ducts will do just as well.

The above factors all tend to furnish a method of test that is almost unbelievably sensitive, searching out a weak spot perhaps several inches in length in a line miles in length. A careful study of the conductivity of various types of cable faults during their progressive stages of formation is necessary before an exact estimate of the efficacy of this method of test can be made. Such a study will involve serious difficulties. The study would, obviously, have to be made in the laboratory on short lengths, for it is impossible to locate faults on long lines during their initial stages of development, without first reducing them by burning, thereby destroying the desired evidence. In laboratory study the faults would have to be artificially formed and might not represent the same type as those formed in service. When the laboratory and field experiences are combined we may, in time, hope to see this method of test reach its full development and furnish a reliable means of preventing short circuit on all types of transmission and distribution lines.

**W. N. Eddy:** In testing insulation with direct current, the question naturally arises as to what d-c. voltage should be used.

It is known that a gap in air will break down at a d-c. voltage equal to the a-c. maximum or 1.41 times the a-c. effective. It is known that the d-c. puncture voltage for most solid insulations is higher than the a-c. maximum, that is, the ratio between the d-c. and the a-c. maximum is often greater than 1.0. The ratio is known to decrease with increasing temperature and also

to vary with the type, dimensions and arrangement of the insulation and even with the method of application of the voltage.

At present the ratio to be expected on any given type of insulation cannot be foretold without making actual d-c. breakdown tests on samples of the insulation.

A detailed investigation of the causes and reasons for the variation of the d-c. to a-c. ratio that is being carried on, has made such progress that it will be possible to publish some exceedingly interesting and valuable results on this subject in the immediate future.

**S. J. Rosch:** The cable user seems to have neglected one very important factor in cable work, and that is, the importance of insulation resistance.

On reading over some of the earlier text books and papers on the subject of dielectrics, I find that insulation resistance had been considered of no moment when referring to impregnated paper insulation. Several of the papers recently published however, have shown that the insulation resistance of cables which have been impregnated in a given compound, has a definite relation to their dielectric loss.

I bring this point up, to point out another line of investigation to Messrs. Phelps and Tanzer, in conjunction with the work they are now doing on cables. While presenting his paper, Mr. Phelps stated that after he had made his voltage tests on the cable, he could find no evidence that the latter had been overstressed. The question in my mind is, how can he tell when a cable has been overstressed? As known to most of you, insulation resistance varies inversely with temperature. If we were to take a certain cable whose insulation resistance happened to be about 300 megohms per mile, subject it to a certain test voltage, and if upon the completion of this test voltage, we should find that the insulation resistance had decreased to about 200 megohms per mile, there would be two ways to account for this decrease. (1) The temperature of the cable had been increased. (2) The insulation of the cable had been overstressed.

Analyzing these two possible explanations, we would have to discard the first, because it would be practically impossible for the temperature of the cable to change ten or even five degrees within a period of five minutes, without the external application of heat, so that the only other explanation in this case, would be that the insulation had been overstressed.

In my opinion therefore, the tests which are now being conducted by Messrs. Phelps and Tanzer, are incomplete if they do not measure the insulation resistance of their cables before and after the application of the voltage tests. As to the feasibility of making these tests, I want to say that insulation resistance is not necessarily a laboratory measurement. The writer has personally measured insulation resistance in the field, by setting up a galvanometer on a tripod, and has obtained very good results that way.

**H. L. Wallau:** It has just occurred to me that this method of testing laminated insulation in cables might possibly be carried out and applied to laminated insulation in high-voltage generator armatures and transformers.

If we could determine the proper time to rewind an armature before it failed in service, it would be of great value to us.

**E. D. Tanzer:** Mr. Roper, in presenting some additional information on tests, similar to those which we have made in Philadelphia, calls attention to the large difference between the initial input current and its final value and cites a particular instance in which the ratio was approximately 15 to 0.1 or 150. I find this to be generally true that the condition of the cable insulation determines more or less the ratio between the initial input and the final value of the current. We have felt that on different types of cables, especially on the new types of cables having inherently better insulation, that perhaps more refined methods of reading these current values would be necessary in order to obtain sufficiently accurate data.

We do not believe, however, that this will nullify the theory that we have proposed, that is, that the inversion of the current-time curve is a measure of the condition of the cable insulation. Dr. Steinmetz has very clearly and interestingly presented the conditions taking place in the insulation of a cable, from the time of initial excitation to the time at which the input current becomes nearly constant. As it was pointed out, there is evidently an accumulation of charge in the cable insulation, and this is responsible for the slow transient that occurs. I am very much interested in Dr. Steinmetz's method of analysis and hope that he may find it convenient to present this in greater detail at some future time.

Mr. Rosch, speaks of a point which we have not fully covered in the paper, *i.e.*, whether or not the method of test imposes any undue stress upon the cable. He has presented to us a point which we can welcome and take up in the work which is now being undertaken in Philadelphia along this particular line, that is, to find out if possible, if there is any difference in the insulation resistance before and after our method of test on a particular cable has been made.

I would like to call attention, however, to the fact that this particular method of testing we have proposed is essentially a routine field test and not a laboratory test. Consequently, we are not able to hold any one of the fifty-seven variables exactly constant as might be done in the laboratory, in as much as it is a routine proposition applicable to field results only.

I am rather interested in Mr. Wallau's point in regard to the application of this method as a possible means of testing armature windings and things of that sort. I personally believe, as does Mr. Phelps, that this method of test does have a possibly wider application than we have made of it. Up to the present time our experience has been confined to cables of one particular class, that is, those having insulation of impregnated paper. I understand, however, that some further corroborative evidence in regard to rubber insulated cables has been secured elsewhere at this time, although the data era not available to be released just not. So far as I can see there would be nothing which would prevent the application of this particular method of testing to other insulations.

The only thing to which I would again call attention is the probability of refinement in the measurements of the current values which might be necessary as the insulation to be tested becomes better and better. As the insulation resistance is steadily increased, then along with the increased value of the impressed voltage necessary, the current to be measured would be less and less, and accordingly more refined methods of measuring this current would undoubtedly be necessary, or at least very desirable.

We believe that in the near future that we will be able to predict an impending fault, at a longer interval of time before it becomes a menace to the system than we are now able to do. This development will be in the nature of refinements in the method of conducting the test and will not mitigate against the method of test at all.

## THE MEASUREMENT OF POWER IN POLYPHASE CIRCUITS*

(Fortescue), New York, N. Y., February 16, 1923.

**R. D. Evans:** The proper method of making measurements on polyphase circuits has been the subject of considerable discussion within the last few years. With balanced circuits, the methods were rather generally accepted, but this was not the case with unbalanced circuits. It is recognized that if the definitions and methods of measurement for polyphase circuits were to have any assured standing, they should cover the unbalanced circuit. Unbalanced polyphase circuits were not well understood, and consequently there has been a lag in the development of corresponding measuring systems.

A method for analyzing unbalanced polyphase circuits was

*A. I. E. E. Journal, 1923, Vol. XLII, March, p. 205.

presented before the Institute by C. L. Fortescue in his paper on "Symmetrical Coordinates". Subsequently, it is found that the various quantities used in the analysis of the unbalanced circuit could be measured. In the present paper, Mr. Fortescue has applied this method to the question of the measurement of power for the general case of the polyphase circuit, viz., the unbalanced circuit. Three conclusions of this study may be stated as follows: 1. The present basis for the energy charge is not fundamentally correct, and a new basis is proposed. 2. Power factor should be defined as being distinct from unbalance. 3. The use of an unbalance factor is desirable in metering polyphase circuits when there is appreciable unbalance.

That the present basis for the energy charge for electrical power is open to criticism may be surprising, the explanation however, lies in the fact that the special, rather than the general case of a polyphase circuit has hitherto been given consideration. Mr. Fortescue has pointed out that a customer with rotating machinery on the same line with a customer drawing a large single-phase load such as an electric furnace load, will have an energy charge in excess of that which would occur if the loads were balanced. Instead of employing the present basis for the energy charge, it would appear more equitable to charge the furnace customer with the energy which he consumes and also with the energy which he causes to be dissipated in the rotating machinery, and at the same time, not to charge the rotating machinery customer with the energy dissipated in the damper windings of his machines, due to unbalance. Mr. Fortescue proposes to do this very thing by basing the energy charge on what he terms "positive sequence power". This charge is in reality based on a component of the total power in the system, which quantity may be measured by a wattmeter of the ordinary type with suitable supplementary net work. As has been pointed out, this method would not appreciably modify the aggregate energy charge, but would distribute it more equitably. The success of the system proposed, will depend in a large measure on the reliability, simplicity and cost of the necessary metering equipment. Some of these metering devices will be described and their operation will be explained in a general way.

The method proposed by Mr. Fortescue for analyzing unbalanced circuits is based on the fact that any unbalanced system may be resolved into two or more balanced or symmetrical systems. For example, in a three-phase three-wire circuit an unbalanced system of current may be resolved into two symmetrical three-phase systems, in which the currents of one system reach their maxima in the different phases in a positive sequence as A, B, C, and the currents of the other system reach their maxima in the negative sequence C, B, A,. The method used here of resolving currents into components, positive and negative sequence, is similar to the method now in general use for resolving currents into components in phase or active, and out of phase or reactive. The reason for the resolution of the currents into components for the two cases are the same, viz., that the different components have different effects, thus simplifying the solution of the problem. Each of these phase sequence quantities if present on a polyphase circuit may be measured. The method of separating out these components is accomplished by the use of suitable supplementary net works. In general, the method for measuring these phase sequence quantities is based upon a separation of positive and negative sequence components of voltages and currents, which are used separately for the measurement of sequence voltages or currents, or which are used in combination for the measure of sequence watts, reactive watts, power factor or unbalance. The method may be described for a positive sequence device as involving a meter element in connection with a net work such that positive sequence voltage or current will cause current flow through the meter element and negative sequence voltages or currents will not. Similarly, the negative sequence device consists of a meter element in connection with a net work such that negative sequence voltage or current will cause current to flow through the meter element and positive sequence voltages or currents will not. A detailed explanation of the operation of some of the simpler forms of phase sequence devices was given before the Institute by the speaker in a paper relating to the definition of power factor on unbalanced circuits. The *Electrical World* has recently published an explanation of the operation of the sequence devices.

The speaker is however, interested principally in pointing out the type of measuring devices required for these phase sequence quantities. For simplicity, only devices for the three-phase, three-wire system will be shown. In Figure 1, the sequence voltmeter devices are shown diagramatically. The meter on the left measures positive sequence voltage and

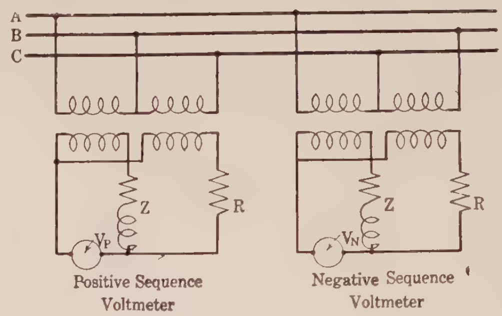



FIG. 1

consists of a meter element, a resistor and a reactor which constitute the supplementary net-work, and the potential transformers. The negative sequence voltmeter is shown on the right and the same apparatus is involved only a difference in connection is required. In Figure 2, the sequence current devices are shown diagrammatically. The positive sequence ammeter is shown on the left with ammeter element, resistor and reactor, which constitute the supplementary net work and the current transformers. If both positive and negative sequence voltages of a circuit are desired, they may be obtained from one set of potential transformers as shown in Figure 3. The corresponding devices for measuring positive and negative sequence current are shown in Figure 4. The schemes shown in

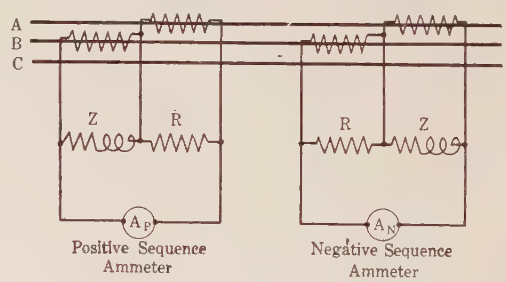


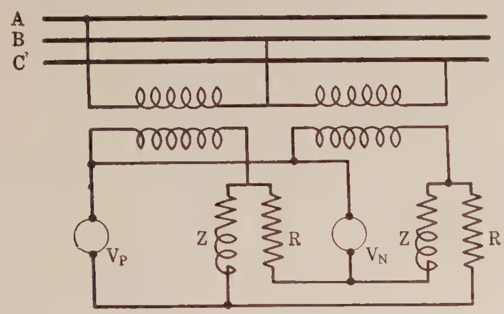

FIG. 2

Figs. 1 to 4 inclusive indicate how positive and negative sequence voltages may be separated and measured independently. These net work arrangements may be used to separate the sequence voltages and currents which may be combined to measure for example, positive sequence watts. In Figure 5 is shown positive and negative sequence wattmeters. The positive sequence wattmeter is shown on the left with negative sequence wattmeter on the right. *R* and *Z* represent resistors and reactors which consitute the supplementary net work.

With reference to the sequence devices in general, the speaker wishes to emphasize that standard types of meter elements or relays and standard types of instrument transformers may be employed. The supplementary net work consists only of resistors and reactors. By these means, reliability and accuracy

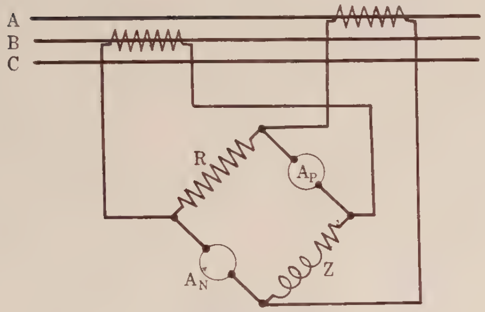
are insured. It is to be pointed out that the form of net work restraint here employed is of a type permitting higher accuracy, as reactors without resistance or resistors without reactance are not required.

With the proposed sequence system, there will result either more complete indication of circuit conditions or fewer metering elements. With the sequence measuring system, there are particular advantages resulting from the use of the quantities thus made available. For example, Mr. Fortescue has proposed



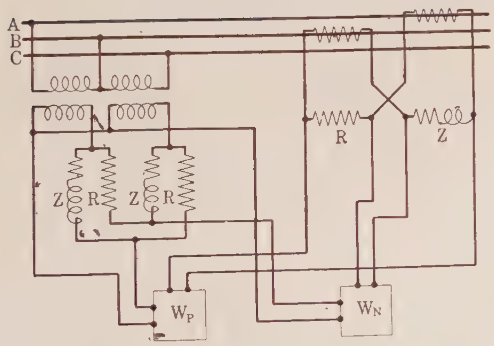

Positive and Negative Sequence Voltmeters

FIG. 3




Positive and Negative Sequence Ammeters

FIG. 4




Positive and Negative Sequence Wattmeters

FIG. 5

that the energy charge be measured by the positive sequence wattmeter. Another example is the application of the negative sequence current device as a relay to provide protection against single-phase operation of motors.

In conclusion, the speaker wishes to emphasize the simplicity of the sequence measuring system. In considering the application of the proposed system of measuring devices, there are two cases to be considered. First, with no unbalance present, in which case, the proposed system and the present systems give the same result, and the proposed system has the advantage of employing fewer metering elements than used with the present system. Second, with unbalance present, in which case, the two systems will give different results, and it is probably desirable to give special consideration to unbalance, which is best measured by the system proposed.

**V. Karapetoff:** I fully realize the importance of the principle of resolution of an unbalanced polyphase system of currents or voltages into two balanced or symmetrical systems of opposite rotation; and this method has been and will be in the future of inestimable value in numerous problems. However, when it comes to a proposal to use this system for charging customers for energy consumed or even for the maximum demand principle, I believe there will be difficulties which are well-nigh insurmountable. The very necessity of convincing regulating bodies, public service commissions, of the soundness of this principle would be a big job. Besides, the average consumer will have to understand what is meant by two systems of opposite rotation, and that the energy of each system has to be charged for, and how much he ought to be charged.

This matter has been presented and discussed at length at one of the preceding Annual Meetings, and as a result of that discussion, I tried to evolve a different principle of metering, perhaps not so sound theoretically, but one that may be much more easily understood by an average consumer of energy, and by an average member of a public service commission. I shall illustrate this principle by means of a hydraulic analogue.

The three horizontal lines $A$, $B$, $C$, in Fig. 6 represent pipes

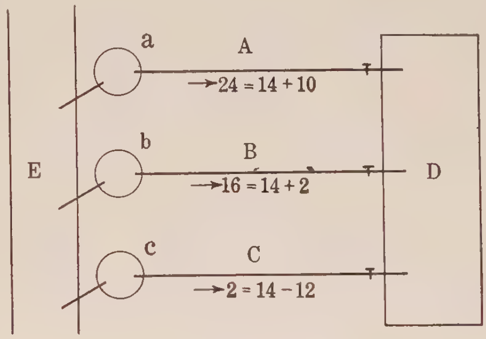



FIG. 6

through which water is being delivered to a common reservoir $D$ at the following rates: 24 gallons per minute in $A$; 16 gallons per minute in $B$, and 2 gallons per minute over the pipe $C$. The pumps are denoted $a$, $b$, $c$, and the common intake is $E$.

Here is an analogue of an unbalanced polyphase system. The consumer needs $24+16+2=42$ gallons per minute; but instead of opening the three valves uniformly, the operator opens one valve wide, another less wide, and the third one just a little until he gets a total of 42 gallons per minute. It is an easy problem to explain to the manager that it makes a considerable difference from the point of view of the pump and pipe equipment whether $42/3=14$ gallons per minute is delivered through all the three pipes, or 24, 16 and 2 respectively. We surely will not say, "What difference does it make to you as long as you deliver 42 gallons per minute." We, as engineers, feel that the consumer of that careless type ought to be penalized.

Now, the question is how much should a consumer be penalized who opens one valve wide, and another a little, as compared to what he would pay had he opened the three valves to the same extent? This, and not two opposite vector rotations, is a right kind of approach to the men to whom we sell electricity, and to those who govern the rates at which it is sold. In the figure, 24 can be replaced by 14 plus 10; 16 can be replaced by 14 plus 2; and 2 can be replaced by 14 minus 12. That is, in each pipe we resolve the actual discharge in each pipe into the uniform flow 14, plus or minus the excess or deficiency as com-

pared to that flow. We can explain to the consumer that what he does is this: He takes 14 gallons per minute through each pipe; that makes 42. In addition to this, he creates a *circulation of water*. This circulating water flows at the rate of 10 gallons through $A$, 2 gallons through $B$, with a common return through $C$. If the pumps $a$, $b$, $c$, are good only for 14 gallons per min., then additional pumps have to be installed because of the unbalance. Of course, these pumps will merely churn water, without lifting it to his reservoir, but any practical man will agree that if in addition to taking water at a uniform rate, he forces the producer to install pumps to circulate water, he has to pay for it. He can also see that the rate for this additional unbalanced water should be different from the rate which water is delivered to his reservoir for consumption.

From this mechanical analogue, a system of metering has been developed, which permits of separating the average flow of electric energy actually consumed from the energy that is merely circulated due to unbalanced load. By using another set of meters, with their potential windings in quadrature, the reactive energy unbalance can be determined. With such meters installed, you can read the energy consumed, the energy circulated, the reactive energy that is uniform, in the three phases and the amount of reactive energy circulated. It remains only to multiply each by the agreed unit rate and to add the results.

**E. P. Peck:** The two papers, one on Measurement of Power Balance in Polyphase Circuits and the other one, Kilovolt-ampere Demand Measurement, are very distinct technically, but in their application they merge, because they both work back into the question of measuring something that you are going to sell and the determination and application of a rate for what you sell.

The rate, to be workable, must be understandable, and it should be simple. As brought out in one of the papers, there were 418 rates investigated; 59 of them had power factor clauses, and a relatively few of those 59 power clauses were actually enforced in the collection of the bills.

We made an investigation somewhat similar to this in which we found that a good many companies were not putting in power factor rates, and very few of the companies that have power factor rates were enforcing them. Apparently this is for the reason that a business man or a manufacturer could not be made to understand what power factor was. Horse power means something to him, but even the terms "kilowatt" and "kilowatt hour" give him considerable trouble.

One of the men in the Company came down to my office a few months ago, and he said: "I have been with the Company for years and years and I have heard of power factor for years and years. Now, can you tell me in about five minutes what power factor is?" I talked about fifteen minutes, and he said he understood what power factor was in a rather general way.

You cannot, in general, use a factor in your rate which cannot be understood by a man who is paying money for his service; he must understand what he is paying money for.

For that reason, the more recent proposal of changing to a kv-a. rate, particularly for demand, is appealing. You can explain, so that a man can understand what you are talking about, what the kv-a. is, and if he can understand and see the justice of paying on a kv-a. basis, you do not have the objection that you would have otherwise.

Now, in the proposal of including another element—the unbalance in the rate, I think, as Dr. Karapetoff just brought out, you are bringing in something that is still less understandable, and therefore still less applicable. I do not believe it could be applied at all. That would set up a rate with an energy charge, an unbalance charge, and the power factor, or a kv-a. charge.

It appears at first glance, or as far as I have been able to see, unnecessary to apply an unbalance charge, for the reason that at certain periods you can check up on your circuits, readjust the taps on the circuit, so as to get an approximate balance. That has been the standard practise in different companies with which I have been connected for a number of years. The result is that the circuits are always commercially balanced.

It appears inadvisable to bring the unbalance factor into the rate for another reason, that is, it is not, as far as I have been able to see, one of the dominant factors in your cost of supplying service, and, of course, your rate is quite largely based on the element of cost of supplying that particular customer.

The distance from the generating station to the customer has a good deal to do with your investment in transmission and distribution; the voltage that you serve your customer at has a large influence on the investment; and, of course, as your investment changes, your carrying charges, and consequently the cost to the company, changes.

A difference in load factor on your plant, whether steam or hydro, has a tremendous effect on your rate; on Sunday night your load is very light, and your cost per kilowatt hour is away up. On Tuesday, at 2 o'clock, when your load is very heavy, your investment is working pretty hard, your steam plant is working efficiently, your cost per kilowatt hour is only a fraction of what it was on Sunday night, and you cannot differentiate between those two conditions.

There are a number of other things that change your costs, not in a ratio of three-quarters of one per cent to one per cent, but change it several hundred per cent.

Since so many of those things have to be absolutely neglected, it would not seem advisable to include a factor in the rate which represented a relatively minor element of the cost. Of course it is advisable to make an analysis of all of these things, so that you have a knowledge of the different factors involved.

I must confess I had not thought of this particular element in cost before, but I do not think that it would work out well in a practical rate schedule.

**R. C. Fryer:** After listening to Dr. Karapetoff's remarks I would like to introduce some ideas from another viewpoint. The metering methods presented by Mr. Fortescue appear to be complicated, however, it is only through close and careful analysis of the most complicated conditions that the simplified conditions can be obtained. It is perhaps best not to discourage the development outlined in such papers as read by Mr. Fortescue but to encourage this development since the actual use of such methods will never take place until the economy of the situation so dictates.

It is quite certain that these fundamentals which are being worked out are not going to be put into use until they are tried and approved. Would it not then be better to encourage such studies knowing that they will lead to a similar analysis which may be the simplified condition so desired?

**W. V. Lyon:** It seems to me that Mr. Fortescue has outlined the effects of power factor and unbalanced factor both from the standpoint of the producer and the consumer of electric energy exceptionally well. There is no doubt that in time, both of these factors will be considered when metering electric energy. In commercial circuits, the effects of harmonics in the electromotive force and current may be disregarded ordinarily and then the readings of recording, active and reactive wattmeters and positive and negative sequence ammeters and wattmeters, may be used in determining equitable charges.

I am also wholly in accord with Mr Fortescue's statement in the first sentence of the appendix. It seems to me that there is need to go no farther than the next two paragraphs for evidence of this belief. It should be said that the quoted sentence had reference, not to the metering of energy in commercial circuits, but to a proper definition of power factor. The aspects of the question may be entirely different when considered from a commercial rather than from a scientific point of view. Definitions and modes of measurements that are good practise may be

entirely unsuited to form the basis of scientific definitions.[1] Thus it is with the quantity $\Sigma\ E_k, I_k \sin\theta_k$. In commercial circuits where the electromotive force and current are sufficiently near the sinusoidal in wave form this quantity is approximately equal to $E_1 I_1 \sin\theta_1$. In this case it is all that Mr. Fortescue claims except that the description of the derivation of its value as shown in equation (6) is somewhat ambiguous. $E_x I \sin\theta$, omitting the subscripts (1), is ordinarily called the reactive power. It is the maximum rate at which energy flows into the magnetic field. It is also equal to the average value of the stored magnetic energy multiplied by $2\omega$, where $\omega = 2\pi$ times the frequency of the electromotive force and current. If the resistance and inductance of the circuit do not vary throughout the cycle, the second of these definitions is still correct even though the electromotive force and current are non-sinusoidal. The first definition, however, fails except when the electromotive force and current are both sinusoidal. If the inductance varies throughout the cycle as does that of a synchronous motor, in which the maximum variation on either side of the average may be as much as 30 per cent, neither of these definitions is in accord with physical facts. As Mr. Fortescue points out, a reactive wattmeter can be calibrated to read the average value of the stored magnetic energy even though the current and voltage may not be sinusoidal, provided, however, the resistance and inductance of the circuit do not vary cyclically. The quantity $\Sigma\ E_k I_k \sin\theta_k$, however, is not even proportional to the average value of the stored magnetic energy, nor to the reading of a reactive wattmeter, except when the subscript $k$ is limited to the value 1, that is, when the current and the electromotive force are both sinusoidal. Furthermore, the product of the electromotive force and current is not equal to the square root of the sum of the squares of the real power and the reactive power, as defined in either of the preceding ways. Neither is this product the square root of the sum of the squares of the readings of an active and a reactive wattmeter except in those cases where the current and electromotive force are both sinusoidal and the circuit constants do not vary cyclically. The point that I wish to bring out is that while the methods of measurement, as sketched by Mr. Fortescue are sufficiently accurate in most commercial practise, they should not form the basis of any scientific definition of power factor.

**F. B. Silsbee:** It is most unfortunate that the ideas which electrical engineers have inherited from the single-phase circuit, have become so fixed along the lines of a separate consideration of the several phases of a polyphase circuit, that a very great deal of mental inertia has to be overcome, before the simpler methods of analysis here presented can come into general use. I feel that several more papers similar to the present one will be required before the metering systems of central stations are changed over to register positive and negative sequence power.

Several years ago a committee was appointed to consider the possibilities of obtaining a definition of balance factor in polyphase systems, but the inherent complexity of the subject, the lack of realization of the importance of unbalance in some cases, and the lack of familiarity with the symmetrical coordinate method of analysis all conspired to produce a general apathy among engineers which, so far, has prevented the adoption of any definite method for treating unbalanced conditions.

In this and earlier papers Mr. Fortescue has suggested the ratio of negative sequence to positive sequence currents as a definition of unbalance, which would solve this problem. While this definition works out perfectly for the case of 3-wire, 3-phase circuits which, of course, is by far the most frequent case in practise, it seems desirable to have a more general definition of which this might be a special case, but which would cover the more complex cases of 4-wire circuits and those of other than three phases. It seems to me certain that such a generalized definition will ultimately be based upon the symmetrical method of analysis, and I trust that Mr. Fortescue will supply us with such a definition in the near future.

**Charles Fortescue:** I want to express my appreciation of the discussions that I have received this afternoon on my paper. Professor Karapetoff always adds lucidity to any subject which he discusses. However, I do not agree with him that the commercial application of this principle presents insurmountable obstacles, and this also applies to the next speaker. Mr. Peek seems to think that consumers are so dull that they will not be able to absorb this idea.

Now, I think that the Public Service Commissions and large consumers can take care of themselves very well. They seem to be investigating a whole lot of things, and they seem to be able to get the right kind of talent. I think they will make out pretty well on positive sequence quantities; and as I am quite sure the principle is right, I am sure that it will prevail.

You know sometimes we do not understand a thing because we do not wish to. The average consumer no doubt is quite dull when it comes to a change in his rates which he thinks is going to be in the wrong direction, and he finds it very hard to understand such things as power factor and unbalance factor.

However, if you ride on any train, you will hear them talking there glibly about detectors, multi-stage amplifiers, feed back regenerative circuits, and so forth—they seem to understand those things very thoroughly, so that I think they must be quite capable of understanding such a simple thing as unbalanced kv-a.

However, should there be any possibility that this method will not come into commercial use, nevertheless it provides a means to enable the rate man to arrange his rates so that they are more equitable; so that no doubt you will find it very convenient to make use of positive sequence devices in the laboratory, and in investigating various kinds of loads.

I believe that there is a real application of these principles, and as Mr. Evans has shown, the principle can be applied with standard instruments, commercial instruments that are used every day.

It does not add any complication; in fact, the tendency is towards simplicity, and moreover, certain conditions do occur from time to time in circuits which demand protection for motors, and this principle affords the best means to give that protection.

## 1922 DEVELOPMENTS IN AUTOVALVE LIGHTNING ARRESTERS*

(Atherton) New York, N. Y., February 15, 1923.

**D. W. Roper:** The designers of the arrester described in Mr. Atherton's paper, having the courage of their convictions that they had a real lightning arrester, were willing to submit it to the scrutiny of the "laboratory" that we have in Chicago, for comparing the performances of various types of arresters.

The results of this scrutiny were entirely favorable. I think it would be quite unsafe at this time to give the arrester our unqualified approval, but there can be no objection to a modest statement that the results so far have been favorable. In fact we are placing more arresters of this design on our lines this year.

The test of this arrester was unsatisfactory in one respect during the past year. From a scientific viewpoint, the results were disappointing because we had so little lightning, the amount being only about 30 or 40 per cent of the average for the past ten years. However, there were one or two storms that gave us some interesting data. In one of them two arresters were affected at the same time. Fig. 1 is a diagram of the installations:

The sketch shows a substation feed system, distribution circuits, four-wire, three-phase, with the grounded neutral. The two arresters, indicated by the $X$'s, were on different circuits, so that there was no actual or line connection between

1. Trans. A. I. E. E., Vol. 39, p. 1515.

*A. I. E. E. Journal, 1923, Vol. XLII, May, p. 485.

the two except around through the station. In one severe storm following a discharge apparently of great severity, trouble was observed at both these locations. One of the arresters was destroyed, but failed to clear itself from the line. It saved the transformer, however, and that is the purpose of an arrester. But it also gave indications of the highest voltage discharge that we have noted in our records up to the present time, so we will hardly call the failure of the arrester to clear itself, a point against it. Apparently that point will be taken care of in future designs.

There is one other practical detail. In one of the slides there was shown a form of contact which I believe very illuminating. This is a form of contact made by taking a piece of bronze and shaping it so as to give a contact and also making a spring connection between the metal electrode at the end, and the disk. A plate, on top, is screwed down on this contact but the lightning discharges are so great that this spring contact is not feasible in a lightning arrester; it will burn through with a heavy discharge. The various makers of arresters who are co-operating in our experiments have all been informed of this fact, so they now use a connection which gives the necessary pressure, and, with another soldered wire connection, provides the proper carrying capacity.

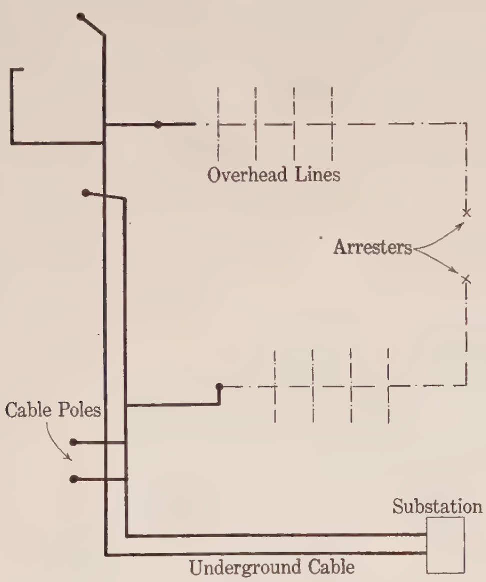



Fig. 1

The remarkable feature of this paper, from my point of view, is the fact that one manufacturing company is applying the principle of the glow discharge to widely different types of apparatus.

**Charles P. Steinmetz:** Mr. Atherton's paper is very interesting in the information it gives on the autovalve lightning arrester, but still more interesting for showing the great progress made during the last year, as the result of the development of the kenotron high-voltage rectifier, in the production of apparatus and methods of testing lightning arresters under representative service conditions. I refer to the "lightning generator", as the apparatus shown in Fig. 7 of Mr. Atherton's paper has become to be called. It consists of a considerable number of large high-voltage condensers charged with high unidirectional voltage from a kenotron rectifier set, and giving a very high power impulse or oscillation of very short duration and of definite predeterminable shape, and so more nearly approaching the direct or secondary lightning discharge than any apparatus available for test. It therefore appears that we rapidly approach the condition when lightning arrester tests will not merely be comparisons of different types, but give exact numerical and reproducable results under specifications which can be standardized, and with an exactness like that of high-potential tests of apparatus for instance. We have given the matter extensive study for a considerable time, and expect to be able at one of the next meetings of the Institute to present a paper on "Methods and Specifications of Lightning Arrester Tests for Service Conditions." Considerable work has to be done to make the use of the lightning generator for testing safe, to determine the limitations of the apparatus; study the methods of tests which are least liable to erroneous results; investigate the possible sources of error and the precaution required to guard against them, etc. For instance, it is little realized what serious effect the inductance of the leads has in retarding the impulse and limiting the frequency; the possibility of erroneous results due to local low-power high-frequency oscillations in isolated capacities such as that of the sphere gap has to be guarded against; the location of the ground is important in its effect on local oscillations caused by the capacity of the system against ground. Also specifications are required on the relation of the spheres to the length of the gap to insure instantaneous action, since even the sphere gap is instantaneous only within a limited range. For instance, the 125 mm. sphere gap in Mr. Atherton's paper asumes a time lag for gaps of less then 30 mm. Furthermore, the development of test gaps of definite and known time lag is desirable to determine the time lag of the protective devices and the apparatus to be protected by them, etc.

**J. L. R. Hayden:** I would like to ask Mr. Atherton about the first curve in his paper, Fig. 1,—whether the data given in this are actual results of tests made at atmospheric air pressure, or whether they are calculated from values observed at lower air pressure. We have been doing a lot of work on these small gaps, and find, it is quite some job to get consistent results down to gaps of one ten-thousandth of an inch. At the same time we found that the proportionality between gap length and air pressure holds for a limited range only, and the voltage of a very small gap can not be calculated from that of a gap of very low air pressure.

**Joseph Slepian:** Mr. Hayden asks about the curve on the first page of Mr. Atherton's paper giving the relation between the breakdown voltage and gap length for very small gaps, and he asks whether it is a calculated curve or an experimental.

It is not a calculated curve, the part to the right of the minimum has been verified experimentally, while the part to the left is obtained by extrapolation, from data from lower pressures than atmospheric. The fact that there is a minumum breakdown for air at atmospheric pressure has been proven experimentally. The experimental establishment of this fact presented great difficulties because with such short gap lengths one must be absolutely sure the gap is free of dust or any loose particles that may get into and bridge the gap. Because of the experimental difficulties there was originally much disagreement as to whether there was or was not a minimum breakdown voltage. The later experiments were done with the greatest care, and show that until you get actual contact the gap will not break down. When I say actual contact, I mean separation of the order of wave-lengths of light. Until separations of that order are reached the gap will not break down with less than 350 volts.[1]

In this later experimental work, small spheres were used. When the gap length was less than this distance of three-tenths of a millimeter, the spark instead of passing between the nearest points of the spheres, would strike from points separated by a greater distance—showing that the smaller distance between the electrodes was stronger dielectrically than the longer path from the sides. Because of this striking of the spark over the

1. *Proc. Roy. Soc.* LXXI., p. 374, 1903; W. R. Carr.
*Proc. Roy. Soc.*, LXXIII., p. 337, 1904; P. E. Shaw.
*Phil. Mag.* (6), 16, p. 456, 1908; J. E. Almy.
*Phys. Rev.*, 31, p. 216, 1910; E. H. Williams.

longer distances, the actual curve showing the increase of break down voltage with decrease of gap length could not be obtained at atmospheric pressures. Results are however readily obtained at lower gas pressures, and the results obtained at the lower gas pressures can be translated into higher pressures by using what is called Paschen's law for the breakdown of gaps in gases. Paschen's law states that for plane electrodes, the breakdown voltage is a function only of the amount of gas between the electrodes. Thus if you halve the pressure of gas and double the distance between the electrodes, the breakdown will be unaltered. That is, lowering the pressure has the effect of increasing the distance corresponding to any particular breakdown voltage. At a low pressure then, the distances become large and manageable so that we can actually experimentally make a complete curve showing the relation between the gap length and breakdown voltage. Curves obtained in this way show that as the separation decreases the voltage falls to the minimum voltage and then rises again. If a series of such curves is obtained for increasing gas pressures, it will be found that these curves are all similar, differing only in that the abscissas representing gap lengths crowd down toward the origin as the pressure increases. The presumption is overwhelming that at atmospheric pressure this continues to hold, except that the dimensions have shrunk down to where it is impossible to run an actual curve experimentally.

Summing up, I may say that experimentally there is a definite proof that there is a minimum breakdown voltage at atmospheric pressures, and by extrapolation from curves taken at lower pressures, there is very definite proof that the voltage rises above this minimum breakdown voltage when the gap length gets sufficiently short.

**K. B. McEachron:** The application of the flow discharge to lightning arrester service as demonstrated in Mr. Atherton's paper is very interesting. We have been in the habit of associating the glow discharge with currents of very small value and it is surprising, indeed, that an arrester built on this principle should be able to handle thousands of amperes even for a very short interval of time.

As a matter of fundamentals, I would like to ask the author what determines the change from the glow discharge to the arc discharge with a given area of electrode. If it is a question of current and time, which in this case means energy, what is the relation between these quantities which marks the borderline between the glow and the arc discharge?

I am also interested in knowing the method used by the author when he found as a result of test that a current of several thousand amperes passed through the arrester before the sphere gap connected in parallel with the arrester broke down. In other words, how was the speed of the arrester measured?

**A. L. Atherton:** There are one or two points brought out on which comments are desirable. First, I want to acknowledge the assistance that was rendered us in the development work by the cooperation of Mr. Roper in Chicago. We were very fortunate to be able to place the trial arresters of his system where he has collected data for comparison and where his ideas are so definitely crystallized. One point which he has brought out is of special interest. During the season three failures occurred among the trial arresters installed in Chicago. A close examination was made of the arresters and every indication was that those failures were by flashover outside of the column of disks between the casing and the column. On calculating back from the line characteristics and the arrester characteristics, it developed that the surge voltage to cause such a failure must have been extremely high, as stated by Mr. Roper. In fact, it probably was a service condition that would result in the failure of any type of distribution arrester now available. However, we have felt it advisable to make changes to raise the flashover point since a ready means was at hand. Moreover, an increase has been made in disk area since the trial arresters were built so that the protection afforded has been increased to about double or a little over, giving voltages at the arrester something under half those which were encountered in the trial installations in Chicago. These two changes increase the factor of safety against flashover many times.

Dr. Steinmetz, in speaking of the test, brought out a point of great interest and one on which a great deal of work has yet to be done. The matter of proper timing of measuring gaps is hard to handle, and the results are rather obscure and hard to translate. Of course, in practically all of the tests that are made on lightning arresters in the laboratory, measurements are made with gaps of which the timing is under control.

The results reported in the paper were selected as rather startling because the gaps that were used in those tests were without any retarding means. They were as rapid as they could be under the test conditions. It is an interesting and valuable point that the results secured with such gaps checked reasonably with what would be expected from the characteristics of the material put into the arrester. That simply demonstrates that the arrester itself is a very high-speed device.

The general question, mentioned in one discussion, of the heat generated in the gaps and the effects to be anticipated from this heat is best evaluated by reference to the tests. Single-column distribution-type arresters have been subjected to repeated discharges of approximately 7000 amperes which is several times the maximum current anticipated in service, and with a duration of the order of that of the surges met in service. After many such surges, tests and visual examination showed the disks to be unchanged.

It is also interesting that this same sort of energy concentration is present in all high grade arresters, since the same energy has to be handled by all arresters with equal discharge resistance. In general, if we assume the manufacturer's descriptions to be correct, in the types of arresters in which puncture of solid material takes place in operation, the energy is concentrated more than it is in this arrester since the total current is stated to flow through a few small punctures. In the autovalve arrester the discharge is very definitely spread out over the area of the electrodes. This brings us to the first question raised by Mr. McEachron. The form of discharge between given electrodes is, as pointed out in the paper, determined by the electrode temperature. This naturally varies with power input and duration. In any given discharge the temperature gradually rises and, if the power and duration are sufficiently above service conditions, the electrode temperature will reach that required for an arc. At this time quantitative data as to limits are not fully available. It is established however that maximum anticipated service conditions, excepting direct strokes of lightning must be greatly exceeded before the glow discharges change to arcs.

As to the inference of speed of the arrester from the tests with parallel gap, it is a safe assumption that if the gap with no series resistance breaks down first the arrester will not break down, for the voltage across the gap is low after breakdown and the gap with leads is a small part of the total circuit. But the arrester did break down. Therefore its speed is of the order of that of the measuring gap.

## A DIAPHRAGMLESS MICROPHONE FOR RADIO BROADCASTING*

(Thomas) New York, N. Y., February 15, 1923.

**R. L. Jones:** I believe we would all find ourselves in substantial agreement with Dr. Thomas in respect to the first four conditions which he sets down as those which must be met by a high quality telephonic reproducing apparatus. It is to be regretted, however, that he does not give data to show how well the glow discharge transmitter fulfills them: data as to its physical efficiency; frequency response characteristics; and its

*A. I. E. E. Journal, 1923, Vol. XLII, March, p. 219.

load capacity, or the degree of linearity with which it responds over a wide range of intensities. The general idea of a telephone transmitter depending upon ionic discharge is old,[1] but this is the first time, to my knowledge, that a telephone transmitter depending upon the phenomenon has been utilized practically. The world is eager for better tools of communication, and the impetus lately given by radio and public address systems stimulates interest. If the glow discharge transmitter fulfils even a part of the fundamental conditions better than other available types, it is probable, in spite of the high-voltage supply and other operating disadvantages, that it will have a certain field of use. In view of the present lack of data showing its performance under the variety of actual conditions, however, it remains for the future to reveal what place it has.

Referring to Condition 5 of the paper, the most flexible and upon the whole the most desirable system is not one where distortion in one element is compensated in another, but rather one with elements as nearly perfect in quality as possible. One of the other papers on the Convention program[2] explained the manner in which distortion in line and cable circuits can be compensated by means of network structures or attenuation equalizers associated with the lines. The possibility of designing modulators, detectors, and amplifiers having practically horizontal frequency characteristics has been demonstrated; and coming down to the terminal instruments, the trend of the development of improved transmitters and receivers is in the direction of instruments which are in themselves reproducers of high quality. In such an instrument frequency distortion is usually symptomatic of conditions which give rise to load distortion at intensities lower than it would otherwise be possible for the instrument to reproduce. This matter of load distortion is an important consideration with public address and radio systems, and one which has not received consideration generally as pointed out in the paper referred to above.

The author of the paper has concluded that neither the condenser type nor the carbon type of telephone transmitter is suitable for such high quality pick-up work as that in connection with radio broadcasting. After relating his experience he says of the carbon transmitter, "It was felt that such devices are by their very nature unsuited to the purpose in hand." And again, after relating defects experienced with a model of the condenser type, he says, "It thus became apparent that the production of a diaphragmless microphone would be a distinct step forward." From these remarks one not intimately familiar with the communication art might fairly conclude that the type of telephone transmitter which employs a diaphragm is in a state of decline and that, with the growing requirements for high quality, the diaphragm type of instrument is moribund. In view of this it seems advisable to supplement the paper by giving some information regarding the characteristics, and the extent of use of two high quality transmitters employing diaphragms, which have been developed recently. These transmitters have had considerable use mainly in connection with high quality public address systems and with radio broadcasting work in the Bell System.

Transmitters of these two types are described in another of the Convention papers presented yesterday.[3] The condenser transmitter consists essentially of a thin steel diaphragm which is stretched and spaced at a distance of 1/1000 of an inch from a rigid plate which constitutes the second electrode. The carbon transmitter similarly employs a stretched steel diaphragm, and has a push-pull construction with two granular carbon resistance elements. It would be desirable to tune both instruments in such a way that their resonance frequencies were above the voice range. In the condenser transmitter this is actually accomplished. In the carbon transmitter, the region of resonance is designed to be in the upper part of the voice range and is so flattened out by high damping that in conjunction with the high frequency of tuning satisfactory quality of reproduction is obtained.

Neither instrument is as high in sensitivity as the ordinary telephone transmitter, and with the condenser instrument a vacuum tube amplifier is always associated as a part of the transmitting set. The quality of the latter instrument is indicated by the fact that the range of variation of its response over a region from 200 to 6000 cycles is less than three miles.[4] In the case of the carbon transmitter, the range of variation is about twelve miles. From other investigations it is known that the range of variation of ear sensitivity of normal persons frequently varies over ten miles in this frequency range, so that a reproducing system, the variations of which do not exceed this limit may be considered entirely satisfactory for high quality work.

The author mentions difficulty with maintaining insulation resistance of the condenser transmitter and a tendency for the diaphragm to sag. Due to construction of the instrument a sag even as small as one mil would cause complete short circuit and the instrument would become inoperative. In view of this fact it seems probable that the author refers to the diaphragm giving somewhat, and thereby lowering its natural period. We have had no such experience in the Bell System laboratory. Instruments have been found with their normal tuning and otherwise in good condition after approximately four years of rather hard laboratory service. In addition to a substantial number of instruments in use for various laboratory purposes, there are three of the leading radio broadcasting stations employing condenser transmitters regularly, and some of these instruments have been in service for nearly a year. While it is true that the insulation of the instrument will vary somewhat, if proper precautions are taken no more difficulty should be experienced from this source than in the case of other elements common in circuits characterized by weak currents and high amplification. It is our experience that there is less difficulty due to the insulation of the transmitter than to that of the wiring of the amplifiers used in systems such as are under discussion. Under careful handling the life of such an instrument should be as great as that of ordinary telephone apparatus. Because of the very satisfactory quality of the instrument and its great constancy, a transmitter of this type is now being favorably considered for use as a reference instrument in laboratory measurements of telephone transmission.

From the author's reference to a fundamental frequency near 800 cycles for the carbon transmitter, it is thought that he has the common form of subscribers' telephone transmitter in mind. This transmitter, which is satisfactory for commercial telephone service where speech alone is transmitted, and where hand receivers are employed, is not suitable for high quality pick-up work, where music must be transmitted, and where transmission must be suitable for loud speaker reproduction. The carbon transmitter developed in the Bell System laboratories for such purposes is free from packing or any other changes of efficiency with time. Its natural frequency is several times the "average speech frequency" mentioned by the author.

Such carbon transmitters are in daily use at about thirty of the most important radio broadcasting stations in the United States, in addition to other frequent use with a considerable number of public address equipments. Altogether there are over two hundred of them out in the field, and after practical experience extending over more than a year, it can be stated that they have made a very good record for themselves, both as to the quality of their reproduction and as to their general serviceability.

**G. D. Robinson:** Mr. Thomas has undoubtedly developed

1. Blyth: Proceedings of the Royal Society of Edinborough, Vol. II, page 622, April 17, 1882.

2. Use of Public Address System with Telephone Lines, by W. H. Martin and A. B. Clark.

3. Public Address Systems, by I. W. Green and J. P. Maxfield.

4. The term "mile" as used in this discussion refers to the attenuation of one mile of standard cable at 800 cycles, corresponding to a relative power ratio of $\epsilon^{-0.218}$

a valuable tool. Although his prime object has undoubtedly been the reproduction of sound frequencies lying within the ordinary range, it appears that this tool might well find use in physics or elsewhere, where the frequency is outside of the ordinary sound range. I would be obliged if Mr. Thomas would tell us anything that he knows about the entreme limiting values of frequency at which this device may be applied.

**Phillips Thomas:** I have to thank Mr. Jones for his very valuable contribution to the discussion. He has brought up many points, on most of which little was said in the paper.

In regard to condition 5, we are I think all in substantial agreement with Mr. Jones, that ultimately we should strive for constructive improvement all down the line, rather than correct, in the final result, inaccuracies occurring at one point by the introduction of inaccuracies at other points. It is, however, a regrettable fact that the present loud speakers, without notable exception, are far from sufficiently perfect to give satisfactory reproduction of undistorted electrical currents. The day of great novelty in radio broadcasting has passed; a large and increasing proportion of radio listeners are musically educated to a surprising degree; and these people will recognize and condemn imperfect results very quickly. The fact that a great proportion of the well-known makes of loud speakers are defective in much the same way, makes it possible to correct at the source, as stated in the paper, and give music-lovers a much nearer approach to desired results than they would receive were all the apparatus to function in a distortionless manner, with the exception of loud speakers.

I am sorry to say that we have at present but little to present in the way of quantitative data on the performance of the glow discharge transmitter as regards variation of sensitivity with frequency or with load. Such data is being gathered as rapidly as possible, and will be presented at the earliest possible moment. We do know, however, that the load characteristic is very good; also that the sensitivity to extremely weak signals is quite as good, as determined by an audibility meter, at 20 cycles as at 4000 cycles, when proper allowance is made for the characteristics of the telephone receivers used.

I am sure that Mr. Jones will agree with me that, other things being equal, the pick-up having the least actual mass of material to be moved by the sound energy will give the best results. The results secured by the use of the condenser type transmitter, for instance, are admittedly superior, when the instrument is at its best, to anything obtainable with even the most perfect double button transmitter, although this superiority may not be evident from the response curves themselves, taken one note at a time. The ability to copy involved sound signals, such as those from a large orchestra, is much greater with the condenser type than with the double button. In fact, in the absence of any better type, the condenser has been taken as the accepted reference standard. A careful comparison between a glow discharge transmitter and a standard condenser transmitter, however, is indeed a revelation. It is surprising, to say the least, how much more natural the result sounds; how every individual instrument of a large orchestra may be as readily picked out as can be done by the ear when listening at the source. We are convinced that this is due, in part at least, to the fact that the glow transmitter is, to all intents and purposes, a point receiver, without appreciable inertia, and at all times critically damped—having no natural period, high or low.

In reply to Mr. Robinson, I am obliged to repeat the statement that we have at present no quantitative data on frequency response curves from the glow discharge transmitter. We have some evidence of a qualitative nature, however, which seems to indicate a very high upper limit to the sensitivity. Although at least so far as we know extremely high frequencies are not transmitted by any existing loud speaker, we are developing an experimental device of this kind, which has a very high upper limit; and we have not been able to find, as yet, the limiting high frequency for the glow discharge microphone, with instruments of this type. As you probably know, the rattling of a bunch of keys fails entirely to be heard through the media of a transmitter and loud speaker of the usual type. Such signals come through in a satisfactory manner, when the condenser type transmitter or the glow discharge transmitter is used in connection with a loud speaker of the experimental type referred to above.

In conclusion, I would say that while there is no intention of detracting from the known good record of the better known types of transmitters, in their field, it is felt that the glow discharge transmitter is a decided step in advance. It is possible, however, that this in turn will be outdistanced by some other form of diaphragmless pick-up which will not have the disadvantage of high operating voltage with its attendant complications.

## RADIATION FROM TRANSMISSION LINES

(Manneback), New York, February 16, 1923.

**V. Karapetoff:** On the second page of Dr. Manneback's paper, on the top of the second column, three conclusions are drawn. The first conclusion is that: "An electric disturbance, *i.e.*, a discontinuity of voltage or current, is always propagated along any line at the constant speed $V = 1 : \sqrt{L.C.}$" And then he adds: "whether there is resistance and leakance or not". I am not sure that this is correct; it seems to me that the velocity of propagation depends on the presence of resistance and leakance and is thereby reduced.

Then, coming to the page on which is Fig. 2, in the second column there is an integral which represents the energy radiated, and this energy is expressed by a finite formula. In Peirce's book on "Electric Waves and Oscillations," in a simpler case of an antenna, a similar result is expressed in the form of an infinite series; and I should like to know just where the difference lies and why in this case a finite expression is possible.

In the treatment of transient radiation on the page on which Fig. 3 is placed, the principle of super-position is used, and I wonder if much of the mathematics in the preceding case of static conditions could not be eliminated by also using the principle of super-position in this form. We already have a formula for energy radiation from a single antenna. Since in this article the effect of the ground is neglected, it does not make any difference whether the transmission line is horizontal or vertical, so suppose we place it vertically. Then the transmission line is analagous to two antennae placed side by side and electrically subjected to disturbances at 180 degrees in time lag. Therefore, if one should write equations for radiation from one antenna and then take a finite difference for the other antennae, one should get the correct result. Since Dr. Manneback does this for the transient condition, I should like to know why it could not be for the static condition as well.

**Joseph Slepian:** I was very much interested in the paper by Mr. Manneback because there has been in the last year something of a dispute in the pages of our Journal between such eminent authorities as Dr. Steinmetz and Dr. Carson as to whether there is really any radiation from a traveling wave on a transmission line. This paper I believe supports Dr. Carson's contention that there is no such radiation. A casual reader might believe that the conclusion of this paper is that there is a radiation but only a small one. However, Dr. Manneback shows that this small radiation is due to ohmic loss, reflections, or anything which prevents the wave from freely traveling and that a freely traveling wave does not radiate energy.

I would like to give an argument for this last conclusion based on a principle of relativity. The principle I shall use is this: that an observer moving with an object both at uni-

*A. I. E. E. Journal, 1923 Vol. XLII, February, p. 95.

form and the same velocities sees nothing different in that object over what he would see if both he and the object were at rest. This is true whether the body is electrically charged or not. Now a freely traveling wave on a transmission line consists of a charge moving with uniform velocity. So far as electrical effects go it is the same as if a charged material object were moving with uniform velocity. An observer moving with this charged object would see nothing different from what he would see if both he and the object were at rest. If both he and the object were at rest we know that there would be no change and no loss of energy from the object by radiation. We must therefore conclude that in the case of the uniformly moving charged object there is also no radiation of energy.

**V. Bush:** Recent progress in radio communication has focused the attention of engineers upon the radiation characteristics of electrical circuits. All a-c. circuits radiate to a certain extent; that is there is a loss in any such circuit, which is caused by the production of waves carrying energy off into space. The filment of an incandescent lamp has a certain small amount of input, over and above that consumed by ohmic losses, which is necessary to provide the energy radiated as heat and light. The radiation from a lamp is caused by the temperature of the filment; that is by the rapid oscillatory heat motion of its electrons. When an alternating current flows in a circuit, the electrons move comparatively slowly back and forth along the conductor. They radiate in each case in exactly the same manner. The waves from the lamp are very short, while those from an alternating or oscillating circuit are very long; but otherwise they are the same sort of waves. When a circuit is designed to radiate a large fraction of its input, it is called an antenna. The length of the waves produced from a circuit depends upon the frequency existing in the circuit. From a 60-cycle circuit, the waves will be 5,000,000 meters or 3100 miles long. The radiation per volt or per ampere from a given circuit varies as the fourth power of the frequency. Hence, at commercial frequencies radiation is ordinarily entirely negligible. An antenna which radiates 100 kw. at a radio communication frequency of 30,000 cycles per second would radiate only 1.6 microwatts if excited to the same potential at 60 cycles. Thus we can ordinarily disregard the effect in our power networks as far as loss of power is concerned.

At high enough frequency, a transmission line may radiate appreciable energy. It becomes a sort of loop antenna. This has been made use of in radio telephone systems for transmission lines, where the line is caused to act as a carrier of the very high-frequency waves which serve the telephone. These waves may be placed on and taken from the transmission line by isolated terminal radio apparatus making use of the radiation characteristics of the line.

It is natural, therefore, to inquire what part radiation plays in the progress of transients of various sorts over transmission lines. Is the abruptness of a switching transient greatly modified by radiation of part of its energy from the line? We know that the steep wave front of such a transient involves rates of current and voltage change corresponding to the rates found at very high frequencies. Is the radiation large as a consequence?

The attack on this problem is attended by one prominent difficulty. Much has been written, particularly of late and by radio engineers and physicists, concerning the radiation from circuits of various sorts, and some of this analysis has been experimentally checked. Practically all of it, however, refers only to the steady state, after transient conditions in the system have entirely died away. It is the effect during the transient period that we wish to examine. Radiation during transients has been little treated except in the classics, and there not for the cases which most interest us from the practical standpoint.

In fact, the very definition of the radiation during a transient is a matter of some concern. Radiation in the steady state is easily defined. When steady alternating potential and currents exist in a circuit, they are accompanied by steady electrostatic and electromagnetic fields surrounding the circuit. These fields constitute a storage of energy. When a field collapses, the stored energy largely returns to the circuit, but not all of it returns. Some of the energy stored in one half-cycle does not return during the next half-cycle. This residual of energy is the energy of the radiated wave, which proceeds out from the circuit at the speed of light. The power radiated from a circuit in the steady state is the energy lost per second in this manner.

In the transient state, we suddenly establish, or remove, potentials and currents. This means the establishment, or removal, also of electrostatic and electromagnetic fields. What portion of the energy represented by the fields thus set up or destroyed shall be considered as radiated energy? When a current is suddenly caused to flow in a circuit, the accompanying magnetic field appears first in the immediate vicinity of the wires. This field then rapidly spreads outward at the speed of light, and finally a field will be produced to indefinite distances. If, while this field is spreading, we examine it mathematically, we find that there is a flow of energy outward. The front of the disturbance carries outward the energy, and spreads it over space as it goes. But if we examine the expression for the total energy in this front of disturbance, we find that it does not tend to zero as the disturbance proceeds to infinity, but approaches a definite finite value. Over and beyond the energy stored in the field, there is thus carried outward an additional amount which moves off indefinitely and is lost forever from the circuit. It is this energy which is the energy radiated during the transient.

In this paper, Dr. Manneback examines the amount of energy thus radiated from a transmission line of usual size and form, where steep transients are involved. He treats the progress of rectangular waves during reflections and at transpositions of the line. The results may be very simply summed up. To engineering accuracy the effect of this radiation may be, without error, ignored in analysis, where the progress of a single steep wave is concerned.

This does not mean, of course, that radiation is always negligible in connection with a transmission line. It indicates only that we cannot depend upon this factor for assistance in reducing its effect of single steep transients. When, for instance, we close a switch at one end of a long line producing a wave which travels down the line and impinges upon the transformer at the distant end, radiation will very little diminish the severity of the impact. If, on the other hand, an arc to ground under certain conditions sets up a steady state of very high-frequency waves, then the effect of radiation may be considerable and very welcome.

The transmission engineer does not deal, after all, simply with a few long wires in which current flows. The effects which he produces and utilizes are spread all over surrounding space. A comprehensive analysis must then deal not only with effects in and between the wires, but also with those fields which are propagated outward from the system. Circuits are, strictly speaking, always three dimensional.

---

## EXPANSION OF OSCILLOGRAPHY BY THE PORTABLE INSTRUMENT*

(Legg) New York, N. Y., February 16, 1923

**J. R. Craighead:** The oscillograph shown represents a combination of elements which have been considered necessary for oscillographic work under most conditions. There is a distinct advantage in getting as many of these as possible into a single device, and making that device as nearly portable as possible.

The statement made by Mr. Legg, that by the development of

*A. I. E. E. Journal, 1923, Vol. XLII, February, p. 106.

this portable device, Oscillographs can now be used everywhere, rather implies that they could not be used everywhere before.

Now, "everywhere" is a pretty broad term, and I do not happen to have any personal experience that goes quite that wide; but I have known of satisfactory work done with oscillographs in factories, foundries, mines, battleships, destroyers, out-doors in the rain, out-doors in tents, and in various conditions where it would seem that a limited laboratory device would be impracticable. The gain from the development under discussion, is not so much a gain in the field where the oscillograph can be used, as it is a gain in the convenience with which it can be transported to that field, and applied, when it is brought there.

In developing this device, considerable attention has been applied to diminishing weight. I have checked up as nearly as I could the elements contained in this device, which is stated to weigh 100 pounds. The latest oscillograph, with full-sized corresponding elements separate from the oscillograph, weighs about 145 pounds. That is a very distinct gain. It is worth while, provided it is not accomplished at a sacrifice of any necessary functions.

In looking through the paper, I find on page 107 certain statements regarding the application of 3000 volts on the 10,000-ohm resistors of the oscillograph. Now, 3000 volts on 10,000-ohms produces 900 watts, and if this element carries one-third of the 1700 sq. in. of radiating surface referred to, this means, roughly, a watt and a half per square inch of radiating surface, evidently an impractical value for continuous service.

I should like to ask the author what is the highest practicable voltage for which this resistance is designed, on a reasonable continuous basis? That is, where the voltage might be on for half an hour, or something of that kind.

On page 108, in reference to the remote control of transients, I note that apparently the transients have been taken at a film speed of 1000 feet per minute, operating a remote control from the oscillograph. This would seem to imply very close timing of heavy switches controlling the circuits through which the transients are obtained. It has been our experience that it is very easy to obtain in connection with the oscillograph, an actuation of an operating circuit to heavy switches, to get transients; but it is not very easy to make the switches work to the limit of two or three one-hundredths of a second, which is absolutely necessary to place the transient in the position you select on the film. Will Mr. Legg give his experience on this point?

On page 110, in respect to operation on chance short circuits. That is a very important field, and if the improvements as designed will enable an oscillograph to catch chance short circuits, a very important addition will be made to our knowledge.

The paper states that the record will show the unreduced value of the short circuit. In most important short circuits, the unreduced value occurs at the actual moment of commencing any short circuit, or at latest, within the first half cycle. Accompanying the above is the statement that the lamp requires something like 0.02 sec. to reach full brilliancy. Without raising the question as to how long it takes to accelerate the motor, in order to get the film up to the proper speed, I should like a little further explanation as to whether it is really meant that the actual beginning of the short-circuit is caught at its full value by this means. If so, we would have added a very remarkable thing to our collection of traps; that is, we would have a trap for short circuits which could be set to catch them, and which would catch the maximum value.

**P. A. Borden:** The shipping weight of 100 pounds as mentioned for this oscillograph particularly impresses me by its comparison with a weight of from 500 to 800 pounds for the portable (?) outfit which it is customary to use when oscillographic tests are required at points remote from the laboratories. In my experience, we have been required to take such apparatus to parts of the country where the services of neither taxicab drivers nor Pullman porters were available. In one instance the equipment was taken to a plant miles back in the woods in the dead of winter, over rough wood-roads where the passage was difficult, even for a lumber sled. In such cases as these, a conveniently portable instrument such as Mr. Legg has described would have proved eminently suitable.

I am particularly interested in the subject of mirrors. We have had trouble in using the ordinary silvered glass mirrors in that they loose their surface, not only when immersed in the damping oil, but when they are in storage. Occasionally we get one that will last for years, even in service, and outlive others that have not been removed from their original package. I understand that the Bureau of Standards, some time ago, developed a mirror made of aluminum; but I have not been able to obtain information as to its practical success. If Mr. Legg or any of the other gentlemen present who are interested in the subject of the oscillograph know anything about the non-silvered mirror I should consider it a great favor if they would tell their experience.

**H. L. Curtis:** There are two points which I should like to discuss, viz., the light source and the mirrors for the moving elements. Mr. Legg uses incandescent lamps, and without doubt they are the most suitable light source for work that he has in mind. However, there is a source which may be used when it is necessary to have a very high brilliancy, provided it is only for a short time. A tungsten wire heated in air to a very high temperature will not burn out for several hundredths of a second. By using such a wire, a higher brilliancy can be obtained than from an incandescent lamp unless a lamp is to be used for each exposure. We have tried this and found one very serious disadvantage in that it leaves a cloud of tungsten oxide over surrounding objects. I hope sometime to have an opportunity of using a metallized carbon filament in place of the tungsten wire. This should be free from the above objection.

The question of aluminum mirrors has been raised. We have undertaken to use aluminum mirrors on the oscillograph, and have successfully made mirrors for that purpose. The means of making them is comparatively simple though the percentage of good mirrors that you get in the process is comparatively small. Cut pieces of sheet aluminum a little smaller than you want the mirror and press these pieces between blocks of hardened steel whose faces have been ground to an optically flat surface. When removed from the press, a reasonable portion of the aluminum pieces will have an optical surface. We are working on the method and hope to improve it.

The real reason for using these mirrors is not because they reflect any better than the mirrors used at present, but we hope that, by the use of aluminum mirrors, we will be able to get sufficient damping by means of the eddy currents in the mirror itself. This will do away with the oil damping and greatly increase the portability of the oscillograph. I cannot say that it is accomplished as yet but it is something to which we are looking forward.

**F. S. Dellenbaugh, Jr.:** We have had a good deal of experience with the portable oscillograph at Massachusetts Institute of Technology. It might be interesting to mention that soon after this machine was delivered we put it in the back of an automobile, drove 1300 miles from Boston to Alabama in six days and put it into operation the next day without any difficulty. Those who have driven two hundred miles a day over southern roads in the Spring will realize that the instrument was extremely strong. In the work we were doing very high-speed oscillograms were necessary and photographs were taken of a transient wave having a period of approximately one thousand cycles and having amplitude of somewhat over one inch upon the film. For this extreme speed it was impossible to use the incandescent light but it was found a very simple matter to substitute an arc lamp. With some device such as that developed by Professor

Turner of Yale for repeating transients it would be possible to use the incandescent light and obtain satisfactory results. The day light loading film holder is a very great advantage for work in the field. I would like to suggest to Mr. Legg that this holder be more nearly balanced so that it could be used at higher speeds without so much vibration. Of course perfect balance is impossible due to the unequal distribution of the film. Another convenience, although not a necessity, would be to have a hood over the viewing mirror since when working in the field reflections from the sky make it difficult to see the curve at times. In general I am extremely glad to see some one developing the oscillograph into a practical instrument which will compare with other metering equipment in ease of operation and reliability. With the large number of graduate students now present at M. I. T. a large number of oscillographs are necessary in order to carry out thesis work of advanced nature. We have three oscillographs in the research laboratory at present and could easily keep three or four more quite busy. The present cost of such equipment makes a large number prohibitive for an educational institution and we would like to see a somewhat simpler model developed which could be bought at a much lower price. For laboratory work it is not necessary to have the control elements self-contained and a very simple outfit consisting of a single vibrator with the simplest kind of shutter and film drum device would meet the requirements in many cases. There is no such instrument upon the market at present and it would appear to me as though it would be extremely useful for smaller institutions and as an auxiliary to the more complete oscillographs for the larger institutions.

**J. W. Legg:** The latter part of this discussion has, to a considerable extent, cleared up some of the questions brought out in the first part.

The paper shows that expansion of oscillography requires more than portability; it requires greater completeness of equipment, greater permanency of adjustments, greater reliability, and greater independence of power supply. The instrument described has all these improvements, and may be transported, as shown by Mr. Borden's discussion, at from one-fifth to one-eighth the weight of previous apparatus of comparable value.

I believe the 145 pounds weight, claimed for previous apparatus, does not include any such resistance as 30,000 ohms. The figure is nearer 4000 ohms. Neither does it include a two-kw. motor-generator set, or bulky 110-volt storage battery, one of which must be obtained if no constant voltage, d-c. power-circuit is available to supply the older oscillograph outfit. The new outfit will operate from any a-c. lamp socket, or from a six-volt storage battery.

The paper states that the 3000 volt d-c. circuit is the exception which cannot be handled by the oscillograph continuously, without external resistor. A 3000 volt peak is very common during switching operations in a 600-volt inductive circuit. The internal resistances of the oscillograph will handle this peak, very nicely, for electric railway tests. The whole 30,000 ohms may be used with one element, without overheating, for recording 3000 volts applied for half an hour or more. Long application of high voltage is seldom required, as control switches may be used to throw on the 3000 volts shortly before taking an oscillogram, and disconnect it immediately after.

Another reason why heating will not be as great as expected, in this oscillograph, is that the vibrator element requires less current per unit deflection, than previous makes, and hence there is less heat given off in the resistors. After four years experience with the included resistors, no undue heating has ever been encountered in commercial testing.

Formerly a day's delay was often caused by the necessity of fixing up a suitable dark room for developing, and reloading film holders. A portable dark room was sometimes carried into the field for these film holders. This added to the already large shipment of carefully packed apparatus. Now we take as many as a hundred oscillograms without resort to a dark room, and then turn them in to the town photographer to develop after the test is over. This daylight-loading feature of the new film holder, surely helps to expand oscillography.

In regard to the remote control of transients; high-speed films are generally required only with quick-acting switches, and slow-acting switches generally require longer exposure films. Such cases are very easily handled with the remote-control device incorporated in the oscillograph. High-speed closing switches may operate in a few thousandths of a second. With the film traveling at 1000 feet per minute the control mechanism may be started seven-hundredths of a second before the opening of the shutter, if desired. Even an ordinary contactor will close in this time, if it is set somewhat closer than usual. Heavy switches, such as oil breakers in high voltage lines, are more sluggish in action, both electrically and mechanically. In order to show the complete electrical transient, the photographic drum must be run much slower. Thus the oscillograph mechanism has ample time to operate the large switch and still cause the transient to appear on the proper part of the film. In case a higher-speed film is required, to study the first part of the short-circuit transient, then the large oil switch may be blocked up so as to be nearly closed, and thus greatly reduce the time required for the magnet to completely close the switch.

Automatic operation, on chance short-circuits, will show the a-c. wave before it is reduced by any breaker action. An actual record is not made of the first a-c. peak, but this maximum peak may be estimated by projecting back the wave according to general laws of transients. In most such tests, the manufacturer is most interested in the characteristics of arc rupture in the oil breaker. These are clearly shown on the oscillogram. The first discernable cycle may be somewhat crowded, due to the fact that the film motor may not be fully up to speed, but this is no material handicap in studying the film.

The problem of keeping the mirrors bright and clear was taken up ten years ago by the Westinghouse company. This company has made mirrors ever since, with considerable improvement in optical efficiency and permanence. One of the vibrators in the first portable oscillograph was not taken from its well in over a year of travel and testing, yet it was just as good, at the end of that time, as a freshly applied mirror on the adjacent vibrator. This is due, partly to the fact that the galvanometer remains at room temperature and hence does not discolor the damping-fluid, partly because the well is made of clear duck-micarta and does not react with the damping-fluid, and partly because a certain clearer damping-fluid may be used since it remains at room-temperature.

At greatest abnormal voltage, the incandescent-filament lamp is operated at the melting point of tungsten, but practice has shown that it is not materially harmed at this temperature provided the application of excessive current is short enough. It is fully up to temperature, as shown by the fact that the beginning of the oscillograph record is just as intense as the end. A continuous half second at this maximum temperature would destroy the filament. Unless a complete quartz optical system is to be used, the writer cannot see any great advantage to a tungsten wire in open air.

A vibrator mirror is not very large in comparison with the vibrator ribbon itself. Hence, as the vibrator ribbon does not introduce appreciable damping, by eddy-currents, it would not seem reasonable that an aluminum mirror would add damping enough to replace the damping-fluid. When the wells are made slop tight, the damping-fluid detracts little from the portability of the outfit.

Mr. Dellenbaugh greatly exceeded the advertised speed limit by taking transient phenomena with a film speed of 2500 feet per minute, with the help of the great optical efficiency of this instrument, and the application of a d-c. arc-lamp. Such a

speed is not recommended, as it required special adjustment of the shutter mechanism for this unparalled film-speed with high-speed transients. A film speed of 1250 feet per minute is often used by the manufacturer. At this speed the incandescent lamp gives abundant light to show up transient phenomena with the main amplitude varying from 3000 to 6000 cycles per second. Only an experienced operator could expect good results at these speeds.

To prevent reflection from the sky, or white ceiling, it is well to place a mirror above the viewing attachment at an angle of 45 deg. This will enable many people to observe simultaneously if they are seated in line with the inclined mirror.

The writer has designed a six-element oscillograph which is even smaller than the three-element model just described. This is to be used for three-phase tests on transmission lines and oil switches. Hence four sets of 5000-ohm resistances and four of 50 ohms is sufficient. The outfit is to be operated on six-volt storage-battery only, and hence has no included transformer. These modifications, and the extremely compact construction of the new permanent-magnet galvanometer-elements, has made it possible to get this complete six-element outfit in a case 9½ by 11 by 25 inches over all, except for the six-volt motor and the film-holder (taking a seven-inch width of standard roll film).

---

## DISSYMMETRICAL ELECTRICAL CONDUCTING NETWORKS*

(Kennelly), New York, N. Y., February 16, 1923

**F. S. Dellenbaugh, Jr.:** The extreme simplicity with which complex circuits may be worked down to a simple circuit is really extraordinary. As you will notice in the bibliography, Dr. Kennelly was the first to publish "The Equivalence of Triangles and Three-pointed Stars," in other words, star-delta transformations in 1899, and it has been a little over 23 years that this process has been known and published, and yet, commercially, it appears to be used very little.

I know a number of commercial cases that I have met with or heard of, that required a very long time, solving networks by the older methods and where, by the use of a star delta transformation, it could be solved immediately, without much effort. In one case, it took an engineer the better part of a day to calculate a circuit by the net work method, that is the older method of Kirchoff's Laws, and so forth, and a young engineer without much experience, but who happened to know this method of Dr. Kennelly's, did this same job in half an hour. The other method made a few approximations as well, while the latter method was accurate.

I think perhaps one trouble is due to the fact that when you have these formulas, the average man does not always know just what to do with them, and while the formulas come down to a very simple looking result, you cannot find out how just to get the numerical answer. If you look it up you find that there are tables of these complex angles and you attempt to use the tables, and find for accurate work, that you have to interpolate. With angles of complex quantities in two dimensions, it is necessary to make six averages to get the final answer, which is laborious.

But in addition to those tables, Dr. Kennelly has prepared some very beautiful charts, and I never think of using the tables any more, because the charts are as accurate as ordinary slide rule work, and you have the very great advantage of seeing the way in which the functions change. Very often, in interpolating from the tables, there is a rapid rate of change, which may make considerable error in a straight line interpolation. Of course, you can use more accurate methods of interpolation, but it requires more time.

I want to make a plea for the use of this method. For those who find it difficult to get results, let them look at Dr. Kennelly's charts of hyperbolic functions, and once the system of going through those charts to find the functions is learned, you will find it is no more difficult to use hyperbolic functions of complex angles than ordinary formulas for the solution of triangles. It involves putting down a few more figures, but it is so much simpler and very much quicker than any method of Kirchoff's Laws, if you have more than the simplest kind of network.

*A. I. E. E. Journal, 1923, Vol. XLII, February, p. 112.

---

# ILLUMINATION ITEMS

By the Lighting and Illumination Committee

## NEW PRACTISES IN STREET LIGHTING

BY A. E. BETTIS

Superintendant of Distribution Kansas City City Power & Light Co.

Two radical departures have been made in the installation of a new street-lighting system in Kansas City, Mo. These are the removal of all street-lighting equipment in each of seven substations, and the placing of a large part of the lamp circuits underground, a special cable buried in the earth without ducts save at street crossings being used. Ducts are used at street crossings to facilitate repairs in case of cable burnouts or other breakdowns. The removal of all of the usual series transformer and switching equipment from the substations means the saving of a great amount of valuable space and in some cases obviated the necessity of special substations for the street-lighting equipment. This in itself has meant a material saving in expense. The placing of the series circuits underground has enabled the use of a simple and attractive ornamental post on streets where there are no street-car lines. On the streets with street-car lines and steel trolley poles, the conductors being carried overhead. The plans which were followed made possible the avoidance of the unsightly wiring and lamp supports that overhead construction usually involves. These results have been attained because it was possible to start with a comparatively clean slate, much of the previous street lighting having been with gas.

Each transformer installation is protected by primary and series fuses. Expulsion-type fuses are employed for the primary side, and the ordinary porcelain cut-out used on 2300-volt service circuits is employed for the series circuit. In addition, two of the same type of cut-outs placed on the circuits may be grounded on either side for test purposes. Compression-type arresters are used on each installation. Separate grounds through driven pipes are provided for lightning-arrester and test purposes. On the 20-kv-a. installations, the normal number of 600-candle power lamps used is forty, while sixty to sixty-five 400-candle power lamps are used on the same size transformer. The 600-candle power lamps are of the 20-ampere type. The 400-candle power are 15-ampere. The 250-candle power lamps are 6.6-amperes, no transformers between the lamps and the circuit being used for these.

Each installation is provided with the markings necessary to identify it, so that record checking and inspection is easy. The standard marker board indicates the substation (*P* is the symbol): *S* indicates that it is a street-lighting circuit and the number is the

number of the circuit. On the primary side the circuit number and the indication that it is a street-lighting service circuit is given. The *RO* number is that of the transformer installation.

Several knotty questions were involved in the selection of cable for the underground work. Duct work except at points like street crossings under pavements, where to save expense of installation tunneling was resorted to, was out of the question on account of expense. Armored cable was the first thought, but involved expense that in Kansas City experience hardly seemed justified. The theory of the armor is that it will prevent street laborers from damaging the cable. Experience has shown that a laborer digging into a cable not only tears off the armor but often takes a considerable portion of the cable with it or damages it so that it must be replaced. The cable finally adopted is easily cut through and damage is thus limited to short pieces. The danger of electrolysis prohibited the use of a plain lead-covered cable, even though this danger is materially lessened by the facts that the cables between lamps are thoroughly insulated from each other and that the total length of any run is very short.

The cable finally selected is lead-covered and has in addition a triple jute covering heavily impregnated. This is expected to provide sufficient insulation to prevent damage from electrolysis to the short runs of cable used.

In the majority of cases the lamp posts used bring the center of the lamp 14½ ft. above the ground, though in one residence district a post with a distance of 11 ft. to the center of the lamp is employed. This is to meet a special condition and is not recommended as a regular practise.

In the base of each lamp standard is a cut-out bolted to a metal support anchored in the concrete. Alongside this support is a transformer with leads running directly to the cutout. The cut-out is made up of a cast iron jacket and a porcelain top carrying the contacts. The cables are sealed into the bottom of the insulated cut-out with compound so that the cable sheaths are insulated from each other. The form of construction is such that in case of an accident which tears the post down there is little chance of an injury to the cable, since the top of the cut-out merely pulls out and the pole and transformer may be jerked free of the foundation without putting any strain on the cable. Moreover, in case work must be done on the installation a dummy top may be put on the cut-out and the pole and all other parts removed without affecting the rest of the installations in service. Any live parts are thoroughly protected.

Generally there is only one transformer installed in these post bases. However, to take care of lights placed in the street to give warning of street intersections, arrangements are made for the installation of a second cut-out in the base of the nearest post, and the circuit for this lamp is carried underground to the center of the street. This makes these warning signs a part of the regular street-lighting system.

Fig. 1—Harrison Blvd. South of Armour Before and After New System was Installed.
Spacing—Lineal feet of street per post—200 ft.—600-c. p. lamps—old system, 100-c. p. lamps.

For trolley-pole installations a special bracket is used which involves no novel features. Care has been taken to get the best possible appearance. For these installations the conductors are run overhead on the trolley poles and the compensators and cut-outs are mounted on the poles above the bracket, the lamp conductors being taken from the compensators to the interior of the pole thence to the bracket.

A variety of conditions had to be contended with so that no statement of average costs would have any meaning. A few costs under specific conditions may, none the less, be of interest. A number of the ornamental posts had to be installed in places where it was

necessary to place the conductors in channels cut in concrete walks. In a typical case of this kind the cost of the post installed complete, including wiring, labor, and all materials up to the cable was $131.00. Anchor bolts were used in the sidewalks to hold the posts in place. The installation of cable in the sidewalks cost approximately 43 cents per foot. Where posts were installed on concrete foundation set in earth the cost complete, including the foundation ran about $130.00. The labor cost of installing the foundation and the cut-out in these cases was approximately $12.00, including excavation. In a typical instance of cable installation which covers a lot of about 12,000 ft. the cost was slightly over 9 cents. This was for the labor of trenching and the cost of placing the cable as well as for replacing sod and otherwise repairing the parking in which the cable was laid. A typical installation cost for cable installed complete is approximately 23 cents per foot. The street crossings where high-grade pavement was excavated cost approximately $2.26 per trench foot complete, including the 2-in. fiber conduit and cable used and the repairs to the pavement. In the outlying districts with the cheaper type of bitumen pavement this cost was approximately $1 per foot.

A large part of the present installation has been operating for nearly a year. In that time almost no trouble has occurred outside of accidents incident to traffic, as where posts are run into and knocked down. One case of trouble with a cut-out due to a loose connection has been recorded. In several instances laborers employed on other street work have dug into and done minor damage to cable.

The ordinance under which the work of installing the system was carried out was passed in May, 1921. It provides the following schedule of prices for the various types of lamps used:

For 600-candle power series street lamps, equipped with "Novalux" units, supported by posts at an elevation of 14 ft. 6 in, from the ground and supplied from the underground circuits, necessitating channeling or excavation in sidewalks in order to install the necessary underground cable; price per lamp per annum, $78.

For 600-candle power series street lamps, equipped with "Novalux" units, supported by posts at an elevation of 14 ft. 6 in. from the ground and supplied from underground circuits, necessitating channeling or excavation in grass plats in order to install the necessary underground cable; price per lamp per annum, $69.

For 400-candle power series street lamps equipped with "Novalux" units, supported by posts at an elevation of 14 ft. 6 in. from the ground and supplied from underground curcuits, necessitating channeling or excavating in grass plats in order to install the necessary cable; price per lamp per annum, $58.

For 600-candle power series street lamps, equipped with "Novalux" units, supported by brackets on trolley poles and supplied from overhead circuits; price per lamp per annum $57.50.

For 400 candle power series street lamps, equipped with "Novalux" units, supported by brackets on trolley poles and supplied from overhead circuits; price per lamp per annum, $48.

For 600-candle power series street lamps, suspended from mast arms attached to wooden poles and supplied from overhead circuits; price per lamp per annum, $55.

For 250-candle power series street lamps, suspended from mast arms attached to wooden poles and supplied from overhead circuits; price per lamp per annum, $34.

For 100-candle power multiple street lamps, supported by posts and supplied from underground circuits; price per lamp per annum, $24.

For 100-candle power street lamps used in "traffic standards," now installed or to be installed by the city at street intersections. In case the city shall furnish, install and maintain at its expense all "traffic standards" referred to in this class of street lighting, the company shall extend its lines to supply such street lamps and will at its expense maintain the lines, supplying the light and the incandescent lamps; price per lamp per annum, $30.

In this contract the city has the option of purchasing at the end of ten years or any other five-year period thereafter the entire plant, property and equipment devoted exclusively to the furnishing of street-lighting service at the cost to the company less the accumulated depreciation at an annual rate of 3.5 per cent per annum at the time the option to purchase is exercised.

### City to Allow Depreciation

Accumulated depreciation shall be reduced to the extent of any reinvestments of depreciation reserve made by the company in its plant used for street-lighting service to the city. Deferred maintenance, if any, shall be considered at the time of purchase. The term "cost to the company" is specified as meaning the original construction cost of the plant and property devoted exclusively to street-lighting service, including a percentage to be agreed upon by the parties at the time of purchase to cover the cost of organization and legal expenses, engineering, interest, insurance, taxes, and injuries and damages during construction. No allowance will be made in the purchase price for going value, franchise value, cost of promotion, bond discount, brokerage commissions, development losses or operating losses. The price to be paid for lamps is to be based on the cost of the posts and glassware used. Any price in excess of this will call for an adjustment of the rates. The city has the right to select the posts, brackets, and glassware to be used.

## SAFE HIGHWAYS FOR WASHINGTON

Electric Road Lighthouses flashing colored signals will dot the dangerous crossings and curves of the several great highways that cross the state of Washington in the near future. An appropriation of $25,000 has recently been made for this purpose by the state legislature.

# The Production of Porcelain for Electrical Insulation-VI

BY FRANK H. RIDDLE

Champion Porcelain Company, Jeffery-Dewitt Insulator Company

***Review of the Subject.****—This article contains several excerpts taken from papers presented at recent meetings of the San Francisco and Los Angeles Sections by Dr. Joseph A. Jeffery on "Modern Methods of Firing High-Voltage Porcelain."*

*The pyrochemical reactions which take place during firing have been described[1]. The firing is done to bring about a complete vitrification of the body to form porcelain. Complete vitrification means no porosity.*

*Firing temperatures are measured by thermocouples, pyrometric cone fusions or measurement of shrinkage bars made of porcelain and withdrawn from the kilns at intervals. Pyrometric cones and shrinkage bars show the effect of time as well as temperature; however, cones are preferable as they can be observed through peepholes while bars must be withdrawn and measured.*

*The two classes of kilns used in firing porcelain are Periodic and Continuous. Periodic kilns have a fuel efficiency of only about 5 per cent, while the continuous kilns not only have a fuel efficiency several times greater than this but also are more efficient as regards production per cubic foot of space required, convenience of operation, labor cost, quality of ware, etc.*

*In firing a periodic kiln the entire contents and inside kiln walls are slowly heated up on a definite time temperature schedule. The air supplied to the burners and fire-boxes is not preheated but is cold, and as soon as the hot gases pass through the ware they are exhausted to the atmosphere and wasted. The temperature of the exhaust gases is only a few degrees lower than that of the ware in the kiln, being anywhere from 1100 deg. cent. to 1400 deg. cent. (2012—2552 deg. fahr).*

*In firing the kilns the heat goes into the kiln through throats and then passes up through the mass of ware conveniently stored in bungs of earthenware containers (saggers). The ratio of the number of saggers close to the fire-boxes where the flames are hottest and longest as compared to the saggers farther away is great and as a result there is no way of giving the ware the same heat treatment in all parts of the kiln.*

*In continuous kilns the car tunnel kiln is used more often than the compartment kiln. There are two main types, direct-fire and muffle. The thermal efficiency of both is obtained in the same manner. These kilns are from three hundred feet to three hundred and fifty feet long and of relatively small cross-section, being about four feet by six feet and so arranged that the temperature at any cross-section is practically the same. The cross-sectional area of a periodic kiln is approximately twelve times as great as the continuous kiln.*

*In these kilns a continuous train of cars of ware passes through in one direction on a definite time schedule. The cars and ware are cold when entering the kiln and are heated up gradually and evenly as they approach the center of the hot zone where the temperature is held constant while the thermal reactions proceed to completion. Then the cars of ware leaving the hot zone are gradually cooled down until they are withdrawn at the exit end cool enough to handle. The air for combustion passes in a counterwise direction to that in which the cars travel. This air absorbs heat from the ware on the cars and not only cools them but also becomes hotter and hotter itself, so that by the time it has reached the fire-boxes or burners it is practically at the same temperature as the firing ware itself. The superheated air combines with the fuel, thus giving a great deal more heat efficiency than it would be possible to get from cold air.*

*These products of combustion continue to travel in the same direction, that is, counterwise to the direction in which the cars go and thus give up practically all their heat to the incoming ware, leaving the kiln relatively cool.*

*The muffle kiln has an added advantage in that it is arranged to keep the products of combustion away from the ware and also to create a vertical flow caused by difference in density of hot and cold air. This practically equalizes temperatures from top to bottom.*

CONTENTS



---

## Firing

No matter how carefully the forming and drying of an insulator have been done, it is still essential that the piece be properly fired. In fact the firing is one of the most important operations in the manufacture. The success of the firing is primarily dependent upon the type of kiln used and the skill with which the kiln is controlled.

The pyro-chemical reactions which take place during firing are very important and must be carefully controlled.[1]

It is not generally known that the application of higher temperatures will convert any porcelain into a glass and that the successful manufacturer of porcelain depends on arresting this process at a very critical point. Due consideration of this point makes one realize the necessity for almost perfect control in order to attain any degree of skill approaching the ideal.

At low temperatures, such as are employed in making lower grade porcelain wares, the feldspar simply acts as a glass to fuse and cement the quartz and clay together. In making high-voltage porcelain, higher temperatures are used and the function of feldspar is quite different as it acts as a solvent and is thus enriched with dissolved quartz and some of the clay substance, the bulk of the latter undergoing dissociation into sillimanite which at first assumes the amorphous and cryptocrystalline form and later develops as needlelike crystals.

Any porcelains of the type used for modern insulators have an exceedingly narrow firing range within which all of their possible properties are best developed.

## Measuring Temperature

The methods of measuring temperature and heat work in ceramic kilns are important and of interest.

1. "The Production of Porcelain for Electrical Insulation" Journal American Institute of Electrical Engineers, Vol. 42, No. 6, p. 631, June 1923.

The three general methods are by use of thermocouples, pyrometric cones and shrinkage.

1. Thermocouples are generally known and need not be described. One point, however, should be brought out in connection with them and that is, that they measure temperature alone and do not show the effect of time upon the ceramic product.

2. Pyrometric cones, Fig. 30, are small tetrahedra about two inches long, having a one-half inch triangular base. They are made from ceramic materials such as kaolin, flint, feldspar, etc., and so compounded in series that each composition deforms by bending at a definite temperature under definite burning conditions. The temperature interval between the softening or bending point of two numbers is practically 20 deg. cent. (36 deg. fahr.). By experimentation it is easy to determine the cone number that deforms when the body has matured properly. This cone and two or three others which mature at lower temperatures are then placed on clay slabs so they will stand in a vertical position between the ware to be fired on the cars and

Before Firing After Firing

Fig. 30

A set of three pyrometric cones of graduated fusing points are fixed erect in a piece of plastic clay ready for placing in the kiln at a point where they can be observed during firing. During the firing the softest cone has fused, the second cone has partly fused and the third still standing as a maximum temperature guide.

so exposed that they can be observed through the peep holes in the kiln. These cones being made of the same types of material as the ware show the effect of the time as well as the temperature effect and hence are reliable indicators, particularly when used in connection with pyrometers, which register temperature alone.

3. Shrinkage—bars or other pieces shaped from ceramic bodies are drawn from the kiln from time to time and the shrinkage accurately measured. It is necessary to know the exact size of the pieces before use and also the shrinkage necessary to show the proper maturing of the body being fired. The so-called Veritas firing rings are used to some extent for this purpose; however, any shrinkage-bar is difficult to draw from the kiln and the chances for error in measuring rather small variations in shrinkage are great.

## Periodic Kilns

During the past few years great progress has been made in the United States in the development of kilns in which porcelain is fired. Gradually the manufacturer has given up the use of the so-called up-draft periodic or beehive kiln. This has been replaced to a certain extent by the down-draft kiln which has been developed to a remarkable degree; and although a very inefficient mechanism (its efficiency being only 5 per cent) it is quite satisfactory for firing many classes of porcelain articles. It is not so suitable for firing high-voltage porcelain which must be neither overfired nor underfired.

In firing a periodic kiln the entire mass is slowly heated up on a definite time temperature schedule. The burners or fire boxes are always supplied with cold air and as soon as the hot gases pass through the ware they are exhausted to the atmosphere and wasted. These instruments are at best very inefficient equipment from a fuel saving standpoint.

Another objection to periodic kilns from a consumer standpoint is that there is no way of giving the ware the same heat treatment in all parts of the kiln and this holds good throughout the entire firing process.

The kilns are heated at uniform rates, but towards the end of the firing it is necessary to hold the temperature and to permit the heat to soak into or saturate the kiln contents as much as is possible, in order to secure reasonably uniform temperature conditions throughout the entire volume. The ware near the throats or bags will have been exposed to a maturing temperature much longer than the ware located in the coolest part of the kiln, and it will also have had a very different gas treatment. As glazes change color with different gas treatments, as well as with different temperatures, visual inspection of the ware or glazed test pieces is not altogether reliable, particularly in view of the fact that it is perfectly possible to have the outside of a piece of porcelain properly fired and mature while the inside is underfired and porous. It seems to the writer that it is better practise to have a transparent glaze through which an inspector can see overfiring defects on the surface, and to resort to other means for determining underfiring in the heart, of the porcelain.

Fig. 31 shows the cross-section of a down-draft periodic kiln with the saggers loaded with ware and in the positions in which they are burned. Saggers are refractory containers in which the ware is placed so as to be piled in bungs or columns for economically filling the kiln and to keep the insulators free from strain. The arrows indicate the paths of the heat, flames and gases as they come up through the throats or bags from the fire boxes and pass around and through the saggers of ware into the flue at the bottom of the kiln and out to the stack.

The construction of the up-draft kiln, more commonly used, is very similar excepting that the products of combustion come into the kiln through the bags and also through an opening in the center of the floor through flues placed under the floor and leading from the fire boxes. The gases rise around the saggers of ware and pass out through properly proportioned openings in the kiln crown into the stack. In this

case the kiln makes its own stack or chimney while an outside stack is necessary with the down-draft kiln. A glance at the cross-section will show that the saggers of ware directly above and in front of the bags are exposed to the greatest heat and most severe treatment. The quality and composition of the gases are also different here from what they are in the center of the kiln, or even up near the crown, where they have become mixed and completely burned. Practically all periodic kilns are fired with natural draft.

For several years careful investigation has been made of the composition of the gases within periodic kilns and much study given to methods of controlling their composition within the desired limits, but this work came to naught owing to the great difference in the specific gravity of the gases involved and the unavoidable contamination or oxidation owing to the leakage of air into the kiln through the combustion regulating devices, and the holes or cracks that are bound to inevitably develop in a structure made of brick and fire clay which is subject to repeated heating and cooling.

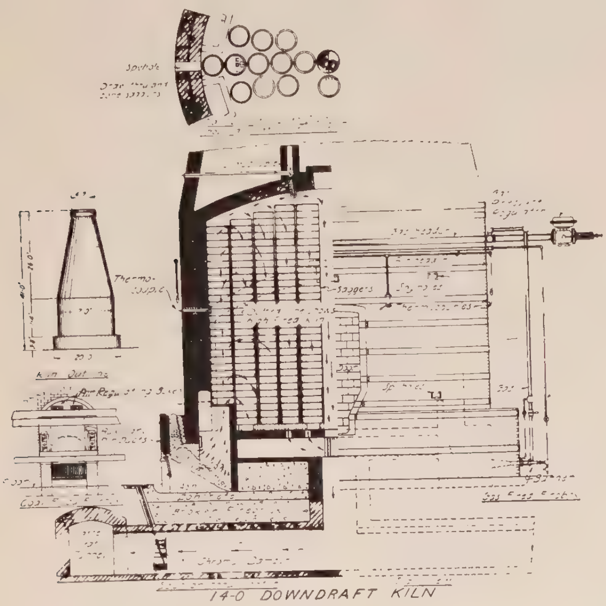



Fig. 31

Cross-section and elevation of a potters periodic downdraft kiln filled with bungs or columns of saggers or containers, each holding an insulator. Note the varying distances of the saggers from the throat of the fire box. Obviously, there must be variations in heat treatment in different parts of the kiln.

## Continuous Kilns

There are two classes of regenerative or continuous kilns, namely, the compartment and the car-tunnel kilns. The latter kiln, however, is the one which has been adopted in porcelain manufacture to the greatest extent.

Some years ago attempts were made to introduce the car tunnel kiln, but it was not until 1916 that a company was formed with a competent engineering force that gave us the first really successful tunnel kiln for the firing of high-voltage porcelain. Since that time the tunnel kiln has made rapid advances and we now have two distinct types: One in which the products of combustion mingle with the ware, the most modern of which is known as the Harrop kiln—Fig. 32; the other known as the Dressler kiln—Fig. 33. In the latter the products of combustion are drawn through combustion chambers permitting the ware which is in a separate tunnel to be surrounded by pure superheated air or gases of any desired quality, without in any way affecting the character of gases in the combustion chambers.

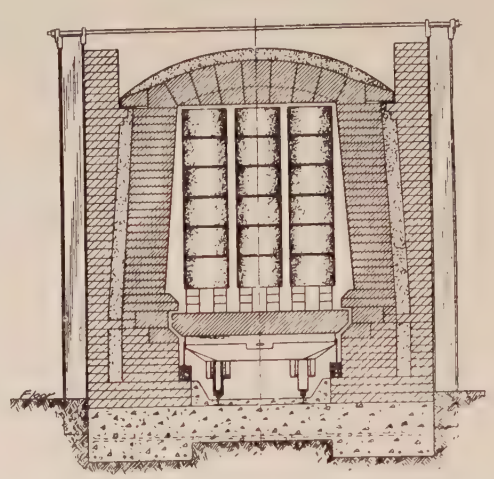


Fig. 32

Typical cross-section of a Harrop open-fired continuous tunnel kiln and loaded car of ware passing through. The inside of the tunnel is about four feet wide by six feet high and usually three hundred feet long.

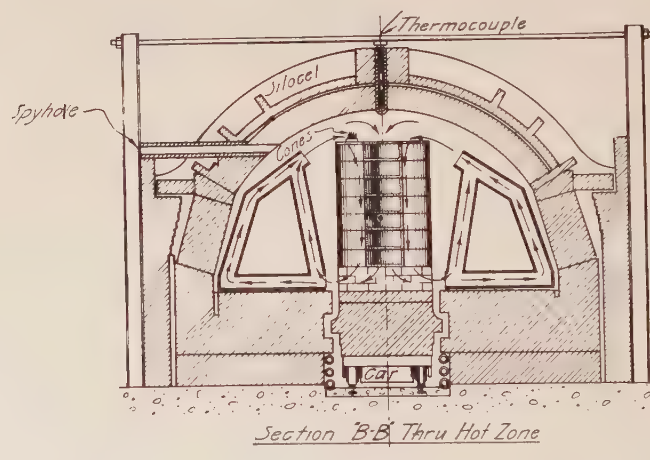



Fig. 33

Typical cross-section through the hot zone of a Dressler muffle type continuous tunnel kiln. Here the products of combustion pass through the carborundum boxes shown on each side of the car of ware and the heat reaches the ware by radiation, convection and conduction and not by direct contact.

The principal argument presented in favor of the tunnel kiln is its great thermal economy. As a matter of fact, the engineers of the Dressler Company guaranteed a saving of 80 per cent of the fuel ordinarily used in the periodic type of kiln. This is not difficult to understand when we consider that the gases toward the

end of the firing in the periodic kiln actually leave for the stack at a temperature of 1100 deg. cent. to 1400 deg. cent. (2012 deg. fahr. to 2552 deg. fahr.), whereas those of the tunnel type of kiln have been cooled by the incoming ware to a temperature as low as 200 deg. cent. to 250 deg. cent. (392 deg. fahr. to 482 deg. fahr.) In addition to this the atmosphere which is to supply the oxygen for combustion is fed to the gas at temperatures from 1100 deg. cent. to 1400 deg. cent. (2012 deg. fahr. to 2552 deg. fahr.), and this superheated air is obtained by drawing air past the cooling ware.

The heat gradient through which the ware passes while being fired and cooled can best be shown by referring to Fig. 34. This is the actual time temperature curve of a tunnel kiln used in burning suspension insulators. The curve is typical of most types of tunnel kilns. Keep this curve in mind in following the description of the kiln.

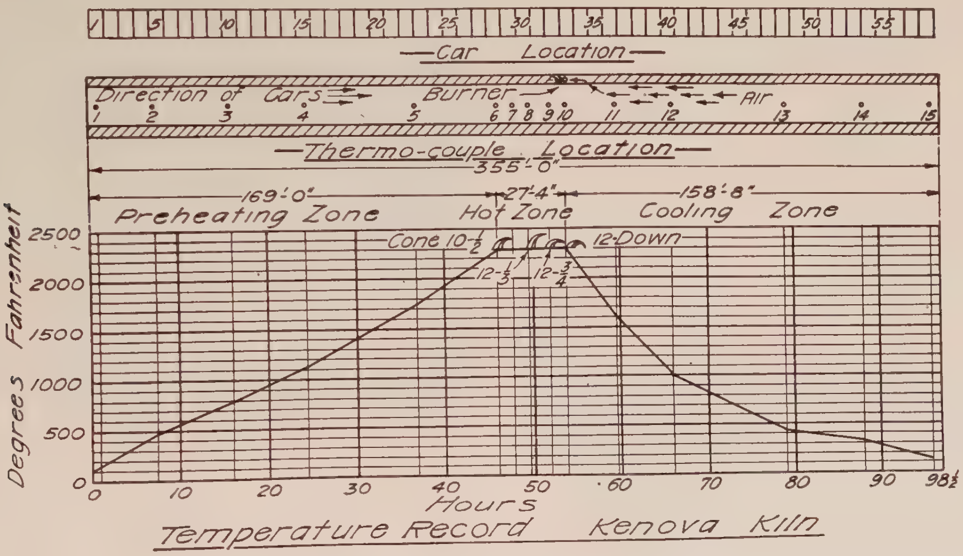



Fig. 34

Time temperature curve used in firing heavy disk insulators in a Dressler continuous kiln. Note the fusion of the pyrometric cones in the hot zone. This shows the remarkable effect of time alone as the temperature is practically constant and yet cone 12 is fused down at a temperature where cone 10 would just fuse if the temperature were not held constant. This permits the vitrification reactions to proceed to completion to the very heart of heavy porcelains where a rapid burn would merely vitrify a crust.

Each type of tunnel kiln has its particular field of application not only to the ceramic industry but also in the heat treatment of steel plate and iron and steel castings where atmospheric oxygen must be excluded. However, some very recent developments in the firing of high-voltage refractory porcelain indicates that there will be some very marked improvements and changes in tunnel kilns in the near future. In this type of porcelain, extremely rigid control of the chemical composition of the gases in contact with the ware is essential. There are several proposed types of kilns for accomplishing this better control and experiments on a large scale are now in progress.

Next in importance to the great thermal economy of the tunnel kiln is its continuous operation. One tunnel kiln of modest dimensions will replace a considerable number of the largest periodic kilns.

The loading and unloading of the tunnel kiln can be made a continuous operation with a very few men, whereas the periodic kiln is generally loaded and unloaded by a larger crew of men in order to reduce the idle hours of the kiln to the minimum.

Another great advantage is the loading and unloading of the cars in a comfortable room while the men loading and unloading the periodic kilns are exposed to very high temperatures and excessive drafts. Fig. 35 shows insulators being loaded onto tunnel kiln cars.

The handling of the saggers containing the ware for a tunnel kiln is a simple operation while in the periodic

Fig. 35

Room in which the insulators are removed from the racks and placed in saggers on the kiln cars. The room is kept within certain limits of temperature and humidity in order to protect the ware from strains and this affords comfortable and uniform working conditions for the men.

kiln the saggers of ware have to be piled upon one another to such a height that they can only be placed by the use of platforms and ladders, and of course during this operation much ware is damaged or subjected to severe strains.

Matters of economy and convenience in the manufacture of porcelain due to the use of the tunnel kiln do not necessarily interest the electrical engineer, but he is interested in the fact that it enables the porcelain manufacturer to develop a porcelain of superior properties at a reasonable cost.

### General Description of Tunnel Kilns

In some respects there is a great similarity between the different types of tunnel kilns. As the name implies, the kiln really is a long tunnel-like structure.

In modern kilns the tunnel is built almost entirely of brick; low-grade fire brick being used in the zones of low temperature; high-grade fire brick near the central zone; and silica or carborundum brick in the high temperature zone. Inasmuch as a considerable length of brick in the tunnel is to be maintained at a red heat and part of it at a white heat, it is necessary to estimate the expansion of the structure very closely and provide suitable expansion joints.

The draft which is to support combustion should always be provided by an efficient exhaust fan with water cooled bearings, the same preferably being driven by a constant speed electric motor. The tunnel kilns should be operated with little or no excess air, and obviously a natural draft stack cannot be depended upon to maintain the draft.

The cars range from 32 inches to 48 inches in width and are generally about 72 inches long. Each car is provided with a tongue on one end and a groove on the other end in the refractory structure, to form a baffle to prevent the radiation and convection of heat between the cars.

If the kiln is of the sand sealed type, the car is provided with a metal flange running the entire length on each side and projecting downward into a trough filled with sand which is located on a bench on each side just above the track. (Fig. 32.)

For non-sealed kilns the car is equipped with a tongue of refractory material which projects into a groove formed in the brick work of the tunnel. This tongue however, provides against radiant heat only, and is not suitable if the air under the car is in rapid motion. (Fig. 33.)

### Dressler Kiln

In the Dressler tunnel kiln an entirely new principle of continuous firing is introduced. The flames do not come in contact with the ware. Essentially it consists of a tunnel which can be divided into two portions: The heating zone which occupies rather more than half the length, and the cooling or annealing zone. In the heating zone, the refractory arch is covered with a thick layer of insulating powder, which prevents the escape of heat from the interior. Inside this arch there are two trapezoidal-shaped chambers placed on a bench on each side of the kiln, and running toward the entrance end. The combustion of the gas for heating the kiln takes place in these chambers near the center of the kiln, and the products of combustion are carried through these chambers toward the entrance end of the kiln by means of an exhaust fan, which is connected through suitable ducts to the chambers on each side.

These chambers are entirely independent of the structure of the kiln and are supported upon a flat bench covered with a thin layer of crushed quartz, thus providing against disruption by the different movement of the combustion chamber during heating, and similar effects owing to contraction in cooling if it is necessary to shut the kiln down for repairs. The ware tunnel through which the loaded cars pass is directly between the combustion chambers.

In effect, the Dressler tunnel kiln is similar to a muffle kiln, as the products of combustion are separated from the ware.

The chambers in the center section of the kiln are made of the highly refractory material—carborundum. The next section is made of refractory material of a composition approximating that of the high-grade fire brick, and the following sections of ordinary refractory composition, and finally the gases are drawn through a series of cast iron pipes, which very rapidly give up the last available heat in the gases.

The fuels in general use are natural and artificial gas and these are introduced with a small amount of air through highly refractory burner tubes. The air supporting combustion which is drawn from the cooling end of the kiln and heated up as it passes the cooling ware until it finally has a temperature varying from 1095 deg. cent. to 1425 deg. cent. (2003 deg. fahr. to 2597 deg. fahr.), mingles with the gas and causes combustion. This mixing is brought about by the aid of a fan which maintains a minus pressure of approximately 0.02 in. of water at the burners and gradually increasing to 0.10 in. at the end of the cast iron pipes. This suction is sufficient to draw the air into the kiln to the burners and then draw the products of combustion on out of the kiln and exhaust them to the atmosphere.

The draft is of special interest, as it is important to maintain extremely low velocities. This becomes more and more important in very high-temperature Dressler kilns where radiation becomes a great factor.

Refractory sliding dampers are provided to accurately control the flow of superheated secondary air, and it has been found possible by close regulation to obtain exhaust gases containing from 16 per cent to 17 per cent of carbon dioxide.

The transfer of heat from the gases in the chambers to the ware on the cars in the tunnel is accomplished by three means, conduction, convection and radiation.

Heat is transmitted directly from particle to particle

by conduction, the particles not altering in their relative positions to one another. The rate at which heat travels from one spot to another depends upon the distance, the difference of temperatures, and the thermal conductivity of the material.

The heat in the case of convection is carried by the actual motion of the air in the tunnel. The motion is

Fig. 36

Looking from the entrance end through the ware tunnel in a Dressler kiln. The products of combustion come through the chambers and cast iron pipes shown on each side. The cast iron pipes at this end permit of an easy transfer of the last available heat from the products of combustion into the ware tunnel.

due to the fact that on heating a gas it expands and becomes less dense, tending to rise, while on cooling it becomes more dense and falls. This is well illustrated by our system of room heating in which we place the steam coils near the floor and depend on the convection of the air to distribute the heat uniformly through the room.

Radiation is the passage of heat across an intervening space. This takes place almost instantaneously, as in the case of the sun's rays, it being understood that reference made here is only to luminous bodies.

In the Dressler kiln, the purpose is to secure the greatest possible efficiency by adjusting the equipment so that the passage of heat takes place under the most favorable conditions. The heat from the gases must pass through the chamber wall by conduction, and there is every advantage in making the walls as thin as possible. They are usually made of carborundum as it has a heat conductivity five times as great as fire brick or clay.

It may be interesting to consider a little more fully how this system of firing by convected heat leads to a great uniformity of temperature throughout the mass of the ware. In the case of the periodic kiln, when the flame has made an upward path for itself among the saggers, this path or flue becomes hotter and draws more and more. As a consequence, it is exceedingly difficult to shift the flame to another and cooler spot, and it calls for great skill on the part of the firemen to create an even distribution of heat throughout the kiln. With the Dressler tunnel kiln, the opposite is the case. The firing is conducted by means of a falling stream of hot air. The combustion chambers deliver a great volume of hot air to the top of the kiln at a temperature very slightly above that at which the ware is to be fired. As the ware is not so hot as this the air is cooled and immediately falls, being replaced by fresh hot air from the chambers. The rate of fall anywhere depends upon the difference in density between the hot air at the top of the kiln and the cooler air at the bottom. The greater this difference, the more rapid and concentrated is the stream. Thus, the effect is automatically to heat up any spot which may be cooler, until it has the same temperature as the ware around it. By the above described mechanism, the zone of the ware at the same temperature as the stream of air delivered to the top of the kiln gradually becomes deeper and deeper, until the whole mass is evenly fired, the circulation of air being finally maintained by the difference in temperature between the top of car refractory base and the flues in the combustion chamber.

In the hottest part of the high-temperature zone of the Dressler kiln there is an extremely rapid heat trans-

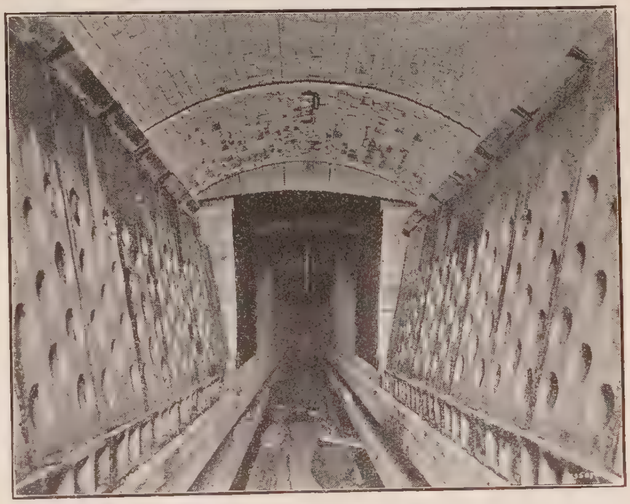


Fig. 37

The hot zone of the Dressler kiln. Looking past the carborundum chambers to the damper boxes and cooling end of the kiln. The air carried past the cooling ware and thus superheated is drawn down into the damper boxes and united with the gas, the products of combustion being carried along in the chambers at each side. Note the "windows" or openings in the outside carborundum chamber walls. These permit the inside walls to radiate heat directly to the saggers of ware in the hot zone.

fer by radiation, it being a well established fact that above 1375 deg. cent. (2507 deg. fahr.) a great temperature differential cannot be maintained if the hot walls of the combustion chambers are actually looking at the surface of the carborundum saggers on the cars. In order to facilitate the transfer of this radiant heat sections of the outside walls of the carborundum cham-

bers are removed so that the heat rays may travel directly from the inner walls of the chambers to the saggers containing the ware Fig. 37. However, convection in this zone is of great importance, and the ware is so arranged on the cars that the superheated atmosphere is permitted to pass freely through the masses, and the introduction of any combustible matter in this zone will quickly indicate a rapid movement of the atmosphere that can only be attributed to convection. The regular firing is thus not dependent upon the skill of the fireman, but is an inherent function of the kiln.

The cooling of the ware is accomplished in much the same manner as the heating and is equally gradual, only the ware is now hotter than the kiln itself, and the air instead of falling rises through the ware to the top of the kiln. It is then cooled by the walls of the kiln and the cooling chambers and pipes, dropping down until it reaches the base of the car, and is then once more sucked through the channels and up through the ware. Since the air is being pulled along into the combustion chamber, there is not the continual circulation of the same air as in the heating zone, but the cold air which enters at the exit end of the kiln pursues a spiral path heating up as it passes the cooling ware until it reaches the entrance to the combustion chamber, where it is drawn in. At no point does the hot ware come suddenly in contact with cold air, and the dunting or cracking which is a great source of loss in other kilns is eliminated. It will be observed that cooling pipes are provided. The necessity for this was not at first realized, but it was found impossible to cool the ware completely with the volume of air required to complete the combustion of the gases needed to fire the ware.

### Uniformity of Heat Treatment

That the heat treatment is substantially uniform for each piece of ware passing through the kiln cannot be doubted when the conditions and operation are summarized. The cross-sectional area is small being about one-eighth to one-tenth that of a periodic kiln and of such a size that it is possible to maintain practically uniform temperatures throughout the cross-section at any point along the kiln. The term "practically uniform" is used here as there is a slight difference in temperature between the top and bottom saggers, the bottom ones being the coolest. This difference is normally not great enough to make any difference in the quality of the ware but sufficient so that if there is any underfired ware it will invariably be on the bottom layer first and at its worst in the center bottom sagger. This is a very valuable quality of the kiln as it makes it possible to select a whole insulator for the porosity test with assurance that if this piece is good every other piece on the car is also good. As the cars of ware pass through each of these various zones at uniform speed and at such a speed that there is sufficient time to complete the pyro-chemical reactions necessary for proper maturity and vitrification, it is evident that the heat treatment for all insulators is substantially the same. It is equally obvious that the same cannot be said of periodic kilns.

## MORE ELECTRIC LANTERNS TO SAEEGUARD RAILROADS

In the last year one railroad company after another has added the electric lantern to its standard equipment. Every transportation company naturally aims at a hundred per cent safety standard and though it is utterly impossible to attain this because "to err is human," it has been found after careful analysis that a mechanical device, such as the electric lantern, can be absolutely relied upon when it is properly cared for. It never "goes to sleep at the switch;" it never gets too tired to do its work; it never complains and it is never faithless.

How many persons, even among seasoned travelers, realize that it is the colored electric lights which make doubly efficacious the marvelous system of block-signaling on roads that have long stretches of electrified service? Moreover, unlike any other lamp, the severity of the elements does not blot out the red, white, or green light which shines clear and distinct through wind, fog and storm.

Not only along electrified sections of the railroads, but also in the railroad yards of divisions where hand-lanterns and miner's head lamps are used, have the converts to electric lanterns shown an enormous increase because of the safety and dependability of this type of lighting element.

## ELECTRIC SERVICE IN FRENCH RURAL COMMUNITIES

In the closing days of the session of 1923 the French Parliament passed a long-advocated measure for the extension of electrical service to rural communities. The desirability of increasing the use of electricity in the country districts has been recognized since long before the war, but some of the consequences of the war—economic and social—have brought even more sharply to attention the advantages which would come from a socialization of the electrical resources of France. It is felt that when electricity is more generally used on the farms there will be a partial relief of the shortage of farm labor caused by the depletion of man power during the war. In addition, the household industries, now hard pressed by manufacturers in the great industrial centers, will be strengthened, thus assuring the continuance of one of the supplemental sources of income which has importance in many of the Departments of France. By the same means it is believed agricultural production may be increased and the general attractiveness of farm life heightened in a way which will help to check the drift toward the cities, which has become even more marked since the war.

# JOURNAL OF THE American Institute of Electrical Engineers

**PUBLISHED MONTHLY BY THE A. I. E. E.**
33 West 39th Street, New York
Under the Direction of the Publication Committee

HARRIS J. RYAN, *President*
GEORGE A. HAMILTON, *Treasurer* F. L. HUTCHINSON, *Secretary*

**PUBLICATION COMMITTEE**
DONALD MCNICOL, *Chairman*
L. W. W. MORROW E. B. MEYER
F. L. HUTCHINSON L. F. MOREHOUSE

GEORGE R. METCALFE, *Editor*

Subscription. $10.00 per year to United States, Mexico, Cuba, Porto Rico, Hawaii and the Phillipines; $10.50 to Canada and $11.00 to all other countries. Single copies $1.00. Volumes begin with the January issue.

Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.




## The Pacific Coast Convention

**DEL MONTE, CAL., OCTOBER 2-5**

The Pacific Coast Convention of the American Institute of Electrical Engineers to be held at Del Monte Hotel, Del Monte, California, promises to be especially good this year on account of the excellent progress made by those who have the affair in hand.

The technical paper situation is being covered by strong committees, and the papers on high tension transmission lines and on radio are expected to be of a high professional grade. In fact, radio matters are going to be especially emphasized, a whole morning being assigned to them, as well as one evening, and it is expected there will be something of interest in radio matters every evening, and perhaps all night for the enthusiasts.

Particularly gratifying is the splendid invitation extended by Mr. R. H. Ballard, vice-president and general manager of the Southern California Edison Company, to the electrical engineers to visit the Big Creek power plants of his company, where several operating high Sierra power plants can be visited, some heavy construction work examined, and one end of the 220 kv. transmission line now in operation to Los Angeles, visited.

Mr. Ballard's invitation on behalf of the Edison Company, covers two days' time, and the Edison Company will provide all transportation and accommodations from Fresno to Big Creek and return, covering Saturday, October 6th, and Sunday, October 7th.

For this mountain trip the transportation committee is arranging for through Pullmans to leave Del Monte at 6 P. M. Friday, October 5th, arriving at Fresno 6 A. M., Saturday morning, giving ample time for breakfast before the Big Creek train leaves at 8 A. M. The charge for this service has not as yet been definitely settled, but probably will not exceed $17.00, including Pullman fare, and the return fare from Fresno to San Francisco of $10.44, including Pullman. The party will be returned to Fresno station Sunday evening, where sleeper connections will be ready, permitting visitors to arrive in San Francisco or Los Angeles early Monday morning.

The technical program is as follows:

TUESDAY, OCTOBER 2

| AFTERNOON | EVENING |
|---|---|
| Registration. | Registration. |
| Outdoor Recreation. | Dancing. |

WEDNESDAY, OCTOBER 3
FORENOON

Registration.
Past-President Jewett's Address.
President Ryan: Researches Relating to High-Voltage Transmission.
Symposium by Transmission Engineers of the Great West on the Mechanical and Electrical Construction of Modern Power Transmission Lines, including Insulators for High-Voltage Lines.

VIEW OF HOTEL DEL MONTE GROUNDS

*Mechanical-Electrical Construction of Modern Power Transmission Lines*, by C. B. Carlson and W. R. Battey, Southern California Edison Company.
*110-Kv. Transmission Line for Oak Grove Development of Portland Ry. Light & Power Co.*, by H. R. Wakeman and H. W. Lines, Portland Railway, Light & Power Co.
*Insulation Design of Anchors and Tower Supports for 110,000-Volt, 4427-ft. Span over Carquinez Straights*, by L. J. Corbett, Pacific Gas & Electric Company.
*Transmission Line Construction in Crossing Mountain Ranges*, by M. T. Crawford, Puget Sound Power & Light Company.

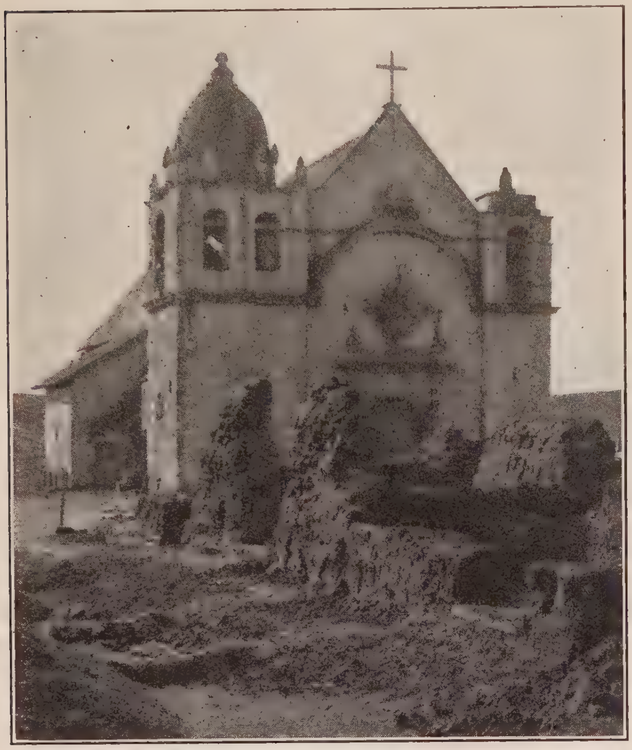
*Group Operation of Systems having Different Frequencies*, by E. R. Stauffacher and H. J. Briggs, both of the So. California Edison Co.

*Special Features of the Design of Transmission Lines as Imposed by Electrical Conditions*, by W. Dreyer, Pacific Gas and Electric Co., San Francisco, Calif.

AFTERNOON

*Symposium by Transmission Engineers of the Great West on Water Wheel Construction, Operation and Governing, etc.*

*Experience with Bearings and Vibration Conditions of Large Hydroelectric Units*, by John Harisberger, Puget Sound Power & Light Co.



HISTORICAL MOUNT CARMEL MISSION

*A Study of Irregularity of Reaction in Francis Turbines*, by R. Wilkins, Pacific Gas & Electric Company.

*Recent Hydroelectric Developments of the Southern California Edison Co.*, by H. L. Doolittle, Southern California Edison Co.

*Upper Falls Development of the Washington Water Power Co.*, by L. J. Pospisil, Washington Water Power Co.

Symposium on *The Practice of High-Voltage Switches, Bushings, Lightning Arresters and Busbars;*

*High-Voltage Switches, Bushings, Lightning Arrester Experience of the Southern California Edison Company on its 60,000, 150,000 and 220,000-Volt Systems*, by H. Michener, Southern California Edison Company;

*High-Voltage Circuit Breakers*, by A. W. Copley, Westinghouse Electric & Mfg. Co.

*Electromagnetic Forces on Bus Supports*, by L. N. Robinson, Stone and Webster, Seattle.

*Test Results on the Performance of Suspension Insulators in Service*, by C. F. Benham, Great Western Power Co.

EVENING

Dancing.

THURSDAY, OCTOBER 4

FORENOON

*High-Voltage Insulation*, by J. L. R. Hayden and C. P. Steinmetz, General Electric Co., Schenectady.

*Power Resources of United States* (an illustrated address), by F. G. Baum, Consulting Hydro-Electric Engineer, San Francisco.

*Waterwheel Generators and Synchronous Condensers for Long Transmission Lines*, by M. W. Smith, Westinghouse Electric & Manufacturing Company.

*Performance of Auto Transformers with Tertiaries under Short-Circuit Conditions*, by J. Mini, Jr., Pacific Gas & Electric Company; L. J. Moore, San Joaquin Light & Power Company; R. Wilkins, Pacific Gas & Electric Company.

*Transformers for High-Voltage Systems*, by A. W. Copley, Westinghouse Electric & Manufacturing Co.

AFTERNOON

Golf Tournament.

17-mile sight-seeing drive in and around Monterey.

Banquet.

EVENING

Presentation of the Edison Medal to Dr. R. A. Millikan followed by an address by Dr. Millikan.

Dancing.

FRIDAY, OCTOBER 5

FORENOON

Symposium on *Radio Communication as Applied to Power Transmission Networks.*

*Carrier-Current Telephony on the High-Voltage Transmission Lines of the Great Western Power Co.*, by J. A. Koontz, Jr., Great Western Power Company.

*Recent Developments in Carrier-Current Communication*, by L. F. Fuller, General Electric Co.

*Some Experiences with a 202-mile Carrier-Current Telephone System*, by E. A. Crellin, Pacific Gas & Electric Company;

*Symposium on Theory and Practise in High-Voltage Operation*, by R. J. C. Wood, Southern California Edison Company. (An address).

*Economic Considerations of Power Factor Control of Long High-Voltage Transmission Lines*, by A. V. Joslin, Pacific Gas & Electric Company.

VIEW ON 17-MILE DRIVE, NEAR DEL MONTE, CALIF.

*Methods of Voltage Control of Long Transmission Lines by the Use of Synchronous Condenser*, by J. A. Koontz, Jr., Great Western Power Company.

*Applications of Long Distance Telephony on the Pacific Coast*, by H. W. Hitchcock, Pacific Tel. & Tel. Co.

*Telephone Transmission over Long Cables*, by H. S. Osborne, Am. Tel. & Tel. Co.

AFTERNOON

Recreation, Sports, Sight-seeing.

EVENING

Leave for Post-Convention Trips.

Visit to San Francisco Bay Region Substations, and Big Creek Development of Southern California Edison Company.

**Hotel Rates**

The rates of the Hotel Del Monte for this convention are entirely on the American plan, and are as follows:

| | | |
|---|---|---|
| 2 persons in 2 rooms with interconnecting bath | $9.00 | per day per person |
| 2 persons in 1 room with 2 beds and bath | 8.50 | " " " " |
| 2 persons in 1 room with 2 beds without bath | 8.00 | " " " " |
| 4 persons in 2 rooms with interconnecting bath | 8.00 | " " " " |

Drive in Hotel Del Monte Grounds

| From | Regular one way fares to Del Monte | Summer exc. fare to San Francisco | Summer exc. fare to Del Monte, limit Oct. 31 | Lower berth to S. F. |
|---|---|---|---|---|
| Vancouver, B. C. | $43.75 | $63.00 | | $13.13 |
| Seattle, Wash. | 37.98 | 54.00 | | 10.13 |
| Tacoma, Wash. | 36.61 | 51.75 | | 9.75 |
| Portland, Oregon | 31.40 | 43.25 | | 8.25 |
| Salem, Oregon | 29.50 | 40.25 | | 7.50 |
| Albany, Oregon | 28.52 | 38.75 | | 7.50 |
| Ashland, Ore. | 19.08 | 23.50 | | 4.50 |
| Redding, Cal. | 12.90 | | $17.25 | 3.00 |
| Marysville, Cal. | 9.84 | | 12.00 | 3.00 |
| Sacramento, Cal. | 7.68 | | 10.00 | 3.00 |
| Fresno, Cal. | 9.30 | | 12.50 | 3.00 |
| Bakersfield, Cal. | 13.20 | | 17.75 | 3.75 |
| Los Angeles, Cal. | 13.74 | | 18.50 | 4.50 |
| San Diego, Cal. | 18.89 | | 25.50 | 5.63 |
| Salt Lake City, Utah | 40.68 | 48.82 | | 9.00 |
| Denver, Colorado | 58.02 | 64.00 | | 16.50 |
| San Francisco, Cal. | 4.44 | | 6.00 | |

One way fare, from point indicated, to Del Monte is shown in each case. Also, from points that are distant to San Francisco, there is a summer excursion rate which is good up to and including September 30th, for going to San Francisco, and good on return until October 31st. Inasmuch as it requires from two to three days to reach this point from the distant locations, members should take advantage of the excursion rate, and leave home on, or before, September 30th. On their arrival in San Francisco they may purchase a round trip excursion rate to Del Monte for $6.00.

From points in California, there is a regular summer excursion rate to Del Monte up to, and including October 31st, as indicated in the tabulation.

Pullman rates given above are for lower berths. The upper berth rate is 80 per cent of that of the lower.

Eastern members desiring to make the trip West will be able to obtain excursion rates up to, and including September 30th, and good to October 31st for return trip.

Baggage should be checked directly to the Hotel Del Monte, Del Monte, Cal.

**Pacific Coast Convention Committee**

The personnel of the Pacific Coast Convention Committee, which is in charge of all local arrangements for the convention, is as follows:

Robert Sibley, Chairman
Allen G. Jones, Secretary
J. C. Clark
H. W. Crozier (Publicity)
Miss C. Grunsky
R. A. Balzari (Registration and Transportation)
H. Y. Bosch, Jr.
H. H. Henline
W. C. Heston (Arrangements)
H. W. Hitchcock
J. A. Koontz, Jr.
W. P. L'Hommedieu
S. J. Lisberger (Papers)
H. H. Millar
R. F. Monges
W. B. Sawyer, Jr. (Entertainment and Banquet)

Cactus Gardens, Hotel Del Monte

## A. I. E. E. Directors Meeting

The first meeting of the Board of Directors for the administrative year beginning August 1, was held at Institute headquarters, New York, on Thursday, August 2, 1923.

There were present: President Harris J Ryan, Stanford University, Calif.; Past-presidents Frank B. Jewett and William McClellan, New York; Vice-Presidents G. Faccioli, Pittsfield, Mass., S. E. M. Henderson, Toronto, William F. James, Philadelphia, W. I. Slichter, New York; Managers H. P. Charlesworth, E. B. Craft, New York, H. M. Hobart, Schenectady, N. Y., Earnest Lunn, Chicago, W. M. McConahey, Pittsburgh,

W. K. Vanderpoel, Newark, N. J.; Secretary F. L. Hutchinson, New York.

Approval by the Finance Committee of monthly bills amounting to $44,313.76 was ratified.

A report of a meeting of the Board of Examiners held July 31 was presented and the actions taken at that meeting were approved. Upon the recommendation of the Board of Examiners the following action was taken: 22 Students were ordered enrolled; 99 applicants were admitted to the grade of Associate; 8 applicants were elected to the grade of Member; 9 applicants were transferred to the grade of Member; 3 applicants were transferred to the grade of Fellow.

Upon recommendation of the Philadelphia Section of the Institute, the Board voted to hold the 1924 Midwinter Convention during the week beginning February 4, in Philadelphia.

President Ryan announced the appointment of committees for the administrative year commencing August 1, 1923. (A list of the committees is published elsewhere in this issue.)

In accordance with the requirements of the by-laws of the Edison Medal Committee, the Board confirmed the appointment by the President of the following members of the committee, for the term of five years ending July 31, 1928: Messrs. Cummings C. Chesney, Robert A Millikan, and Michael I. Pupin. Also in accordance with the by-laws of the committee, the Board elected from its own membership the following members of the Edison Medal Committee, for the term of two years ending July 31, 1925: Messrs. H. M. Hobart, Frank B. Jewett, and W. K. Vanderpoel.

Messrs. C. le Maistre and Guido Semenza were reappointed as Local Honorary Secretaries of the Institute for England and Italy respectively, for the term of two years ending July 31, 1925.

The Standards Committee reported that the translation of the A. I. E. E. Standards into Spanish, previously authorized by the Board of Directors, is now completed and has been approved by the Standards Committee, and that publication of the translation, by the U. S. Department of Commerce as arranged for, would now proceed.

A code of procedure to be followed in connection with the Institute's representation on Sectional Committees organized under the rules of the American Engineering Standards Committee, the approval and adoption of reports of these committees, etc., was adopted as recommended by the Standards Committee.

Upon invitation from the American Marine Association, the President was authorized to appoint a representative upon the General Committee of the American Marine Congress to be held in New York, November 5-10, 1923.

A communication was presented from the secretary of the Award Committee of the Kelvin Medal, inviting the Institute to suggest a candidate for the award of the 1923 Kelvin Medal. This medal is awarded triennially "as a mark of distinction to a person who has reached high eminence as an engineer or investigator in the kind of work applicable to the advancement of engineering with which Lord Kelvin was especially identified"; and the Award Committee consists of the presidents of various British engineering societies. The medal was awarded for the first time in 1920 and upon invitation, the American engineering societies submitted nominations for the 1920 candidate. A similar invitation had been received by the other national engineering societies; and it was voted that the President be authorized to appoint a committee with power to act after conferring with representatives of the other American societies concerned—with the understanding that the Board considers desirable a joint recommendation from the engineers of America and a single name proposed.

Various recommendations adopted at the Section Delegates' conference held at Swampscott, Mass., June 25, during the Annual Convention, were presented and acted upon as follows:

That the Board of Directors give consideration to devising a method of transferring members from lower grades to higher grades for which they are fully qualified through the initiative of other members familiar with their professional experience, and without the necessity of the candidates themselves submitting formal application for transfer. The Board voted to refer this recommendation to the Board of Examiners.

That a plan be adopted that has been under consideration, whereby highly theoretical and mathematical papers that are probably read by a limited number of members, shall be published in abstract in the monthly JOURNAL and in full in pamphlet form for distribution to members who desire them, and in full in the annual TRANSACTIONS, thus making available more space in the JOURNAL for engineering material of a different nature. This was referred to the Publication Committee for consideration.

That at least one meeting be held each year of the executive committee of each geographical district of the Institute, and that the traveling expenses of the members of the committee be paid. The Board referred this to the Finance and Sections Committees to devise a plan, if possible, for the payment of this expense, for report to the Board of Directors.

Reference to other matters discussed may be found in this and future issues of the JOURNAL under suitable headings.

# National Research Council

*Under this heading are included news items of the National Research Council and its activities and summaries of progress made by the research committees of its Division of Enigineering during the current month.*

The purpose of this section is to give a resumé of the progress made during the month and point out the objects and methods of attack for each project.

### WELDING OF OIL STORAGE TANKS

Object: To design a welded storage tank which will enable the reduction of loss of the lighter oils from leakage and evaporation now accruing in the present riveted construction.

Progress: The design of a 5000-barrel tank by both the electric arc and oxy acetylene welding processes have been completed. A report of the electric arc method, including specifications, was published in the December 1922 issue of the American Welding Society. A report on the oxy acetylene welding method has just been completed, and was published in the June 1923 issue of the *Journal* of the American Welding Society. The latter report includes photographs of two tanks constructed according to this method.

---

### APPLICATIONS OF ARC WELDING IN SHIP CONSTRUCTION

Object: To prepare a critical review of the best existing information dealing with the above subject and to compile data which will be useful to the engineer and designer in bringing about economies through such application.

Progress: A comprehensive report has been prepared by Mr. E. H. Ewertz, General Manager of the Moore Plant of Bethlehem Shipbuilding Company, under the guidance of the Electric Arc Welding Committee, and is now being published as a serial in "Marine Engineering." The report includes cost

figures, test data, relative advantages of welding versus riveting, service results of applications and different designs of welded ships.

### ADVISORY BOARD ON HIGHWAY RESEARCH

Object: To assist in outlining a comprehensive national program of highway research and the coordinating activities thereunder, to organize specific projects and to act in a general advisory capacity.

Method: The Board comprises representatives of 17 organizations interested in highways, transport thereon, vehicles and highway organizations. Experimental work involving more than one million dollars is in progress by Federal and State Departments, universities, industries and organizations, the results of which are being made public through the Board.

Recent Progress: Bulletin containing proceedings of the second annual meeting has just been released for distribution. It includes a summary of the development of the Board, a review of the problems of the research subcommittees, a report of the Director, and reports of the various research subcommittees.

### MARINE PILING INVESTIGATIONS

Object: To learn more of the marine boring animals now causing wide destruction to wharves and marine piles, and to devise methods for protection against these ravages. To secure information as to the cause of deterioration of cement concrete in seawater and methods of prevention.

Recent Progress: A paper on "Disintegration of Cement in Seawater" was presented by Wm. G. Atwood and A. A. Johnson at the June 13 meeting of the American Society of Civil Engineers. This report is available as a preprint and will appear in the August *Proceedings* of the American Society of Civil Engineers. It includes a review of literature of cement disintegration and describes foreign experiments, and recommends others in connection with cement in sulphate bearing waters. A resumé of the paper was presented before the annual symposium of the American Society for Testing Materials on Concrete during the latter part of June.

# American Engineering Standards Committee

### INTERNATIONAL CONFERENCE ON STANDARDIZATION

A conference of the secretaries of national industrial standardizing bodies was held in Switzerland, July third to seventh. Thirteen countries were represented, including all of the more important industrial nations of Europe and America. The sessions were held in Zurich and in Baden.

A leading topic discussed by the conference was the interchange of information between the various national bodies during the development of the work in the different countries. At the first conference held in London two years ago, arrangements were made for the systematic interchange of completed work, and to some extent, of information on work in progress. Experience had shown such an early interchange to be extremely important for the work within the different countries from the national viewpoint alone, and quite irrespective of the question of international standardization.

While it was not possible to overcome all the difficulties existing by virtue of the important industrial considerations involved, very substantial progress was made. It is believed that the steps taken will lead immediately to a substantially increased amount of interchange of information during the earlier stages of standardization work, and that the way has been paved for a much more extensive interchange in the future.

Provision was made for continuing the work of the conference on the many administrative problems of common interest, through a loose-knit continuing organization. An example of such work planned by the conference is the translation of technical terms of special importance or difficulty in standardization work. There will gradually be built up such a vocabulary of technical terms, mainly in English, French and German, but supplemented as far as may be feasible and necessary by the corresponding terms in other languages. Another example is the work undertaken by the conference on the classification and nomenclature of standards.

### TROLLEY CONSTRUCTION SPECIFICATIONS

The specifications prepared by the American Electric Railway Association, for 600-volt d-c. overhead trolley construction have been approved by the American Engineering Standards Committee as Tentative American Standard, and the American Electric Railway Association has been designated sponsor for the revision and future development of these specifications.

In the preparation of the specifications, dating back to 1907, cooperation was had from a number of the larger manufacturers of overhead line material, as well as from engineers and contractors. In 1908, the subject was assigned to the first Power Distribution Committee, where it was given the most careful and extended consideration for six years. In 1913 approval was given by the Convention of the A. E. R. A., and in 1914 by the A. E. R. A. Committee on Standards, which consists of fifteen members, nine representing electric railway companies, and six, manufacturing companies. These specifications embody much of the best practise in electric light, power and communication, as well as electric railway service, and it is understood that they have been followed to a large extent by the majority of electric railways as standard construction practise.

In recommending the approval of these specifications, the special committee of the A. E. S. C., headed by Mr. E. A. Frink, A. E. S. C. representative of the American Railway Association—Engineering Division, called attention to the revision of the National Electrical Safety Code now under way. The revision of the National Electrical Safety Code and of the Specifications for Trolley Construction will be carried out, as is necessarily the case under A. E. S. C. procedure, in such a way as to assure their complete harmony at all points where they contain related provisions.

The other organizations represented on the special committee on approval were Electric Light and Power Group, American Electric Railway Association, American Institute of Electrical Engineers, National Bureau of Standards, American Society for Municipal Improvements, American Short Line Railroad Association, and Electrical Manufacturers Council.

## American Electrochemical Society

### TENTATIVE PROGRAM OF 44TH MEETING, SEPTEMBER 27-29, AT DAYTON, OHIO

September 27, 1923, Thursday, A. M.—Technical Session at the Engineers' Club for the reading and discussion of papers pertaining to the Symposium "Electrochemistry of Gaseous Conduction," with Dr. Duncan MacRae, of the Westinghouse Lamp Co., Bloomfield, N. J., in the Chair.

Thursday noon—Group Luncheons, Engineers' Club, followed by Round Table Discussions on the following subjects:

"Electric Furnace Brass Foundry Practice"—H. W. Gillett, Chairman.

"The Development and Future of Electrodeposition"—S. Skowronski, Chairman.

"Organic Electrochemistry"—C. J. Thatcher, Chairman.

"Utilization of Chlorine"—A. H. Hooker, Chairman.

These Round Table Discussions will be informal and members and guests interested are encouraged to take part.

Thursday evening—Outdoor Meeting and Smoker at Triangle Park. Informal talk by Mr. Charles F. Kettering, President, General Motors Research Corp. Entertainment staged by members of the Society.

Friday A. M.—Technical Session continued, Engineers' Club.

Friday afternoon—Visits to plants. Sightseeing trips. Golf.

Friday evening—Lecture at the Engineers' Club on Recent Researches on the Electrochemistry of Gaseous Conduction, by Dr. H. B. Wahlin, of the University of Wisconsin.

Saturday A. M.—Technical session, Engineers' Club.

## PERSONAL MENTION

W. B. Hoschke, formerly of Kittanning, Pa., has moved to Memphis, Tenn., where he has accepted a position with the Phoenix Utility Company.

G. Raymond Flake, formerly Chief Electrician at the Standard Steel Works Company, Burnham, Pa., has resigned this position to go into business under the name of Industrial Electric Company at Lewistown, Pa.

John S. Isdale has resigned from the position of Electrical Engineer to the New York Harbor Drydock Co. Inc., Rosebank, N. Y., to become Sales Manager of the Marine Products Branch of The Horne Electric and Manufacturing Co., Jersey City, N. J.

Leonard A. Doggett, for the past ten years in charge of electrical engineering instruction of naval officers in the Post Graduate School at Annapolis, has resigned in order to take a position in the Department of Electrical Engineering at the Pennsylvania State College, State College, Pa.

Terrell Croft, of the Terrell Croft Engineering Company, has effected an affiliation with George B. Nichols, consulting engineer of New York City, whereby the resources of each organization will be available for clients of the other. Mr. Nichols will act as the principal for projects east of Illinois and the Croft organization for projects west of that state.

John B. Cameron has been appointed as Chief Engineer of the Villazon-Atocha Railroad, being constructed by the Ulen Contracting Corporation, Atocha, Bolivia. He has been in South America for many years, having been engineer, superintendent and general superintendent of construction for the Ulen Contracting Corporation, on hydraulic and railroad work in these countries.

Royal D. Sloan who has served as Assistant Professor of Electrical Engineering at Yale University during the past year has been appointed Associate Professor of Electrical Engineering at the State College of Washington at Pullman. Prof. Sloan is a graduate of the University of Montana, was employed two years with the General Electric Company and later with the Montana Power Company on the Thompson Falls development. During the war he entered the service of the navy and was in charge of the electrical equipment of the Battleship New Mexico with the rank of junior lieutenant. Before going to Yale, Professor Sloan had been Associate Professor of Electrical Engineering at the Montana State College for a number of years.

Graham Bright, formerly General Engineer in charge of mining acitivites of the Westinghouse Company, has joined the firm of Howard N. Eavenson & Associates, Mining Engineers of Pittsburgh, Pa. Mr. Bright has been with the Westinghouse Company almost continuously since his graduation from the University of Pittsburgh in 1898. He is well known in themining and engineering fields, and has been Chairman of the Mines Committee of the A. I. E. E., Chairman of the Mining Equipment Committee of the A. I. M. & M. E., Chairman of the Committee on Underground Locomotive Standardization of the American Mining Congress, a member of the American Engineering Standards Committee, representing A. I. M. & M. E. and a member of its Mining Correlating Committee.

## Obituary

Arthur G. Lund died at Chicago, Illinois, July 21, 1923. He was born at Bradford, Yorks, England, in 1880, and after graduating from Victoria University, England, he was employed by J. Parkinson & Son, Yorks, England; British Insulated & Helsby Cables Limited; and Siemens Brothers & Company. In 1912 he came to the United States and was associated with the G. &. W. Electric Specialty Company, of which he has been head of the Sales Engineering Department for the past ten years. He became an Associate of the Institute in 1912.

Edward J. Hunt, Managing Owner, Edward J. Hunt Manufacturing Company, died August 11, 1923. Mr. Hunt was a graduate in Electrical Engineering of Tufts College in 1892, and subsequently spent fourteen years in various departments of the General Electric Company. In 1913 he established a manufacturing business in Newark, N. J., where he built transformer oil drying and testing apparatus of his own design. Mr. Hunt was inventor of a number of electrical devices. He became an Associate of the Institute in 1921.

Delwyn Dessar, Assistant Engineer, Duquesne Light Company, Pittsburgh, Pa., was killed in an automobile accident on August 1. Mr. Dessar was a graduate of the University of Nevada. He has been connected with the Dela Vergne Machine Company, New York, Nevada Valleys Power Company, and the General Electric Company, Schenectady. Mr. Dessar served in the army during the war in the rank of Captain and after his return was connected with the Sales Department of the General Electric Company in New York. In 1922 he became Assistant Engineer of the Duquesne Light Company of Pittsburgh, Pa. He became an Associate of the Institute in 1921.

## Electric Power Club Meeting

The Fall Meeting of the Electric Power Club will be held at the French Lick Springs Hotel, French Lick, Indiana, on November 19-22, 1923.

## The 1923 Chemical Exposition

Plans for the 1923 Chemical Exposition which will open at the Grand Central Palace, New York, on September 17th and extend for one week, opening daily at noon and closing at 10:00 P. M. are about completed. Outside of the four hundred odd exhibits which are expected by the time the exhibition opens, two other features have been planned for this year. They are a moving picture program of industrial films to be shown each afternoon and evening in a special auditorium for the purpose, and an intensive course in the practical business side of chemical engineering for students in various universities all over the country. Upwards of 200 students have already enrolled for the course at the exposition. About thirty authorities in various fields of chemical engineering will discuss their specialties for the benefit of the students. Prof. W. T. Read of Yale University, is in general charge of the student course feature of the exposition this year.

The discussions of the subjects on the student program will be supplemented by recitation and conference periods, and directed inspection of exhibits. The course will be finally

reviewed in class and a written report will be required by those in charge of the course. It is understood that some of the colleges and universities sending students will allow full credit for work in this course. Columbia University has offered the use of its dormitories for students attending the course.

Thus far, several associations of the chemical industry have arranged to hold meetings during the week of the exposition. The American Ceramic Society will hold a meeting and the Technical Association of the Pulp and Paper Industries will hold its usual fall meeting in conjunction with the exposition at the Grand Central Palace. The regular fall dinner of the American Institute of Chemical Engineers will be held during exposition week at the Park Avenue Hotel, New York. The annual banquet and election of officers of the Salesmen's Association of the American Chemical Industry will also be held during the week of the exposition at one of the nearby hotels.

## Atlas of U. S. A. Electric Power Industry

A most timely book under the above caption has recently been produced by Frank G. Baum, consulting engineer, of San Francisco, which deals with the power resources and the power demands of the United States and presents a well-considered solution of the electric power problem for the entire country. There has been much discussion of super power systems for various regions during the last few years in both the technical and popular magazines and the advantages of superpower systems are very generally recognized. In his new book Mr. Baum goes a step farther and suggests a nation-wide superpower system consisting of large water powers and large economical steam plants interconnected by a constant-voltage transmission system.

The inception of this work was in a paper entitled *Voltage Regulation and Insulation for Large Power Long Distance Transmission Systems*, presented by Mr. Baum at the 37th Annual Convention of the A. I. E. E. at Salt Lake City, June 1921, for which he was awarded the Institute prize for 1921 for the best paper on the subject of electrical transmission. The comprehensive plan outlined by the author hinges on his ingenious method of voltage regulation, which is accomplished through the use of synchronous condensers connected at intervals of 100 or 200 miles to the transmission system. This results in a very flexible transmission system in which power may be supplied to or taken from the line or reversed in direction without disturbing the constant-voltage condition.

The advantages which would accrue from the establishment of a system as outlined by Mr. Baum are exemplified in California, which has the largest interconnected system in the world. Of this, Mr. Baum says:

"Electric service in California is essentially the same in cities of 5000, 50,000 and 500,000 population. And I believe the real solution of the power problem of the country requires keeping this fundamental of practically universal service thoroughly in mind. Electric service is too popular to make it possible long to deny the use of this service to a large proportion of the people, or to have the cost so high in the smaller cities that the growth of the nation must take place in the larger cities. Very large power systems undoubtedly will develop all over the country, and finally make power service almost universal in the United States. If this is to be the case, then electrical men should plan the system some time ahead, and not allow it to grow without general plans as the railways of the United States grew without general and directed plan."

The details of the author's plans are presented by means of numerous maps, charts and tables and are extremely complete.

ATLAS OF U. S. A. ELECTRIC POWER INDUSTRY. By Frank G. Baum, N. Y., McGraw-Hill Book Co., 1923. 57 pp. diagrams, maps. 11 by 17 in. cloth. $10.00.

# Engineering Societies Library

*The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.*

*In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.*

*The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.*

*The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.*

### BOOK NOTICES July 1-31, 1923

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made: these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

ABSOLUTE MEASUREMENTS IN ELECTRICITY AND MAGNETISM.

By Andrew Gray. 2nd. edition. Lond., Macmillan & Co., 1923. 837 pp., illus., tables, 9 x 6 in., cloth. 42s. (Gift of Macmillan & Co., N. Y.)

It is nearly thirty years since the first edition of this well-known treatise appeared, and the new edition should be of interest to all who have to do with absolute measurements, and particularly to workers in wireless telegraphy. Dr. Gray has rewritten his book, omitting certain subjects now adequately cared for elsewhere, and expanding those parts of practical importance today. The work now appears in one volume.

ABSORPTION OF NITROUS GASES.

By H. W. Webb. N. Y., Longmans, Green & Co.; Lond., Edward Arnold & Co., 1923. 372 pp., illus., tables, 9 x 6 in., cloth. $8.50.

In almost all processes for the fixation of nitrogen the production of nitrogen oxides is a fundamental intermediate step. These nitrous gases are usually absorbed in water, but the process of absorption is frequently conducted on rule-of-thumb methods, with unnecessary losses.

The author of this work discusses the absorption of nitrous gases in water, both from a theoretical and industrial standpoint. The most important types of absorption processes, other than water absorption are also considered and compared, and the

methods available for utilizing commerically the dilute nitric acid obtained from water absorption are reviewed briefly.

CARATTERISTICHE COSTRUTTIVE DELLE TURBINE IDRAULICHE NEGL' IMPIANTI ATTUALI.

By Guido Gambardella. Milano, Antonio Villardi, 1923. 133 pp., 10 x 7 in., paper. (Gift of the author)

In this contribution to the literature of the hydraulic turbine, the author is concerned with the correlation of recent theory and current practice and with a comparison between the results of calculation and those obtained by laboratory tests. Theoretical and experimental data furnished by various manufacturers are given and modern features in distribution and regulation are explained. The book is intended for students who wish to understand current manufacturing practices, for purchasers of turbines and for manufacturers.

COSTING AND PRICE-FIXING.

By J. M. Scott-Maxwell. Lond., & N. Y., Isaac Pitman & Sons, 1923. 211 pp., illus., 9 x 6 in., cloth. $2.00.

The purpose of this book is to give briefly the general principles of cost accounting and, in detail, a complete system applicable to a factory manufacturing a large variety of apparatus, relatively to its total output, the great bulk of which cannot be completed and put into stock, but can be only partly manufactured and must be completed after the receipt of the customer's order. Appropriate parts of the system will meet all the requirements of factories that produce finished products and sell from stock, while the complete system can also be applied to plants that work to order only. The principles and system have been used by the author in practice for the past fifteen years.

DIE DRAHTLOSE TELEGRAPHIE UND TELEPHONIE.

By P. Lertes. 2d edition. Dresden U. Leipzig, Theodor Steinkopff, 1923. 200 pp., 8 x 6 in., paper. .70.

This volume is one of a series of books reviewing the progress in various sciences from 1914 to the present time, which is being issued to acquaint German scientific workers with the advances made while their labors were interrupted by the war. The present book treats of radio communication. It summarizes systematically the important publications of all countries, presenting the main results in condensed form and giving exact references to the original papers. Radio engineers should find it a convenient reference book.

L'ECLAIRAGE.

By E. Darmois. Paris, Gauthier-Villars et Cie., 1923. 276 pp., illus., diagrs., 8 x 6 in., paper. 15 fr.

In a volume of moderate size, the author gives a good summary of the present state of the art of lighting. Theory and practice are both included, the intention being to assist architects and others in the intelligent selection and utilization of sources of artificial light. Particular attention is given to industrial lighting.

LES ECONOMIES DE COMBUSTIBLES; CONDUITE RATIONNELLE DES FOYERS.

By Pierre Appell. Paris, Gauthier-Villars et Cie., 1923. (Encyclopédie Léauté, 2e série). 341 pp., illus., diagrs., tables, 8 x 6 in., paper. 17 fr.

The purpose of this book is to call attention to the economies in the use of fuel which are possible in industry and to indicate the methods by means of which these savings may be realized. The author reviews the fuel situation in France, gives directions for investigating and choosing fuels, explains the phenomena of combustion and discusses methods for using fuel efficiency under boilers, in gas producers and in furnaces. Methods of measurement and control are also considered. A bibliography and index are given.

ELECTRIC FURNACE FOR IRON AND STEEL.

By Alfred Stansfield. N. Y., & Lond., McGraw-Hill Book Co., 1923. 453 pp., illus., diagrs., tables, 9 x 6 in., cloth. $5.00.

Instead of issuing a new edition of his "Electric Furnace," Dr. Stansfield has decided to replace it by two new books, of which the present work, dealing with the use of the electric furnace in the metallurgy of iron and steel, is one. It is intended to give a reasonably complete account of the electric smelting of iron ores to make pigiron and the making of steel from metallic charges in electric furnaces.

The book consists of three parts. The first contains historical matter, an outline of ferrous metallurgy and a brief account of the electrical supply needed for electric furnaces. The second part describes the electric smelting of iron ores for pig-iron, the reduction of iron ores in the state of powder and the production of ferro-alloys. The third part treats of the production of iron and steel from metallic materials and the furnaces in use for these purposes. It also includes a chapter on the production of steel from ore and ore electric welding.

ELECTRICAL HANDLING OF MATERIALS, vol. 4: Machinery and Methods.

By H. H. Broughton. Lond., Earnest Benn, 1923. 334 pp., illus., diagrs., 11 x 9 in., cloth. 50s.

This, the concluding volume of Mr. Broughton's useful treatise, has for its subject the machinery used for handling materials mechanically and the methods of handling and storing. The opening chapters describe elevators, conveyors, belt conveyors, automatic feeders and ship hoists. Succeeding chapters are devoted to methods of handling various articles, especially, ore, coal, grain and similar bulk materials, and foodstuffs. Like the other volumes, this one deals broadly with the question of design and gives many examples that illustrate the present state of the art.

ELEMENTS OF GRAPHIC STATICS.

By Clarence W. Hudson and Edward J. Squire. N. Y., & Lond., McGraw-Hill Book Co., 1923. 91 pp., diagrs., 8 x 5 in., cloth. $1.25.

A brief testbook giving the essentials of graphic statics, especially in their application to the calculations of reactions, shears and moments. Intended for students of engineering. Includes only the material thought to be actually necessary for a working knowledge of the subject. Can be covered in about fifteen classes.

ELEMENTS OF MACHINE DESIGN.

By Dexter S. Kimball & John H. Barr. 2nd edition. N. Y., John Wiley & Sons; Lond., Chapman & Hall, 1923. 446 pp., illus., tables, 9 x 6 in., cloth. $4.00.

A discussion of the fundamental principles of design, intended primarily for students, but also, the authors hope, of interest to designers. The principal part of the work is devoted to the discussion of the more important details of machines, with a view of showing how theoretical considerations and equation are applied and modified in practice. The new edition has been thoroughly revised and the arrangement changed as a result of experience. A chapter on the balancing of machine parts has been added.

ESTIMATING THE COST OF BUILDINGS.

By Arthur W. Joslin. 3d edition. N. Y., U. P. C. Book Co., 1923. 212 pp., illus., 9 x 6 in., cloth. $2.00.

A volume upon various matters of interest to contractors. Explains how estimates are prepared for the different classes of work on a building, how sub-contracts are handled and how building operations should be handled. One section is devoted to estimating alterations to buildings.

The buildings referred to are wood or brick structures of moderate size. The directions are clear, full and practical, making the book suitable for students in trade schools and beginners.

HYDRAULICS FOR ENGINEERS AND ENGINEERING STUDENTS.

By F. C. Lea. 4th edition. Lond., Edward Arnold & Co., 1923. 594 pp., illus., tables, 9 x 6 in., cloth. $6.00. (Gift of Longmans, Green & Co., N. Y.).

Dr. Lea's book is intended as a reference book for practising engineers and as a textbook for serious students. He attempts to deal with the subject in a wider sense than is done in most test-books, to embody the results of the latest experimental research on the subject and to give sufficient details to indicate the methods used in obtaining those results.

This edition has been revised to include the latest experiments. The original chapter on turbines has been much enlarged and that on pumps has been divided into two chapters.

INTRODUCTION GEOMETRIQUE A L'ETUDE DE LA RELATIVITE.

By Henri Marais. Paris, Gauthier-Villars et Cie., 1923. 191 pp., 10 x 7 in., paper. 15 fr.

The author of this book has set himself the task of preparing, in a form at once as simple and clear as possible, a sort of grammar of the mathematical language of relativity, from the viewpoint of geometry. He studies successively euclidean space and

the laws of invariance for linear transformations, then Riemann space and the laws of invariance for continuing transformations, indicating the part that these geometric ideas play in theories of relativity. The book is intended to help students of relativity by removing purely formal difficulties from their path, through familiarizing them with the fundamental concepts and processes of calculation.

Les Isotopes.

By A. Damiens. Paris, Gauthier-Villars et Cie., 1923. 118 pp., illus., diagrs., tables, 10 x 7 in., paper. 12 fr.

This monograph, based on a bibliographic study of the literature of isotopy, is intended primarily to familiarize chemists with the subject, but it will appeal also to others desirous of becoming acquainted with the work in this field. The author gives a general account of the whole question, in which all experimental results are presented, their relative value determined and the conclusions to which they lead are pointed out. Full references to sources of information are provided.

Motor Transportation of Merchandise and Passengers.

By Percival White. N. Y., Lond., McGraw-Hill Book Co., 1923. 486 pp., diagrs., tables, 9 x 6 in., cloth. $4.00.

This book considers motor transportation as a rapidly developing business activity. It recognizes and relates all phases, treating, for the first time, both merchandize and passenger transportation by motor vehicle in relation to each other and to other methods. It is intended for owners and operators of fleets of trucks and buses, students of transportation and automotive engineers interested in the economic phases of this problem.

Numerische Integration.

By Fr. A. Willers. Berlin u. Leipzig, Walter de Gruyter & Co., 1923. 116 pp., 6 x 4 in., boards. .25.

This little book treats of the purely mathematical methods of practical mathematics, so far as these deal with problems of infinitesimals. It thus supplements the volume of the Sammlung Göschen entitled "Graphische Integration" and, like the latter, will be useful to mathematicians, physicists, and especially to engineers. The presentation is as simple as possible and requires nothing beyond a knowledge of the elements of the calculus.

The title is to be taken in the broadest sense. Section one contains formulas for interpolation and the methods of tabular differentiation and integration. A short section follows on the formulas of Newton, Gauss and Chebichev. The next section treats of the mathematical analysis of data obtained empirically. The final chapter discusses the approximate integration of differential equations.

Patents Throughout The World.

By William W. White and Wallace White. N. Y., Trade Mark Law Publishing Co., 1923. 244 pp., maps, tables, 9 x 6 in., cloth. $7.50.

In this digest of the patent laws of the different countries, a uniform arrangement of the data under the same headings has been adopted for each country. Ready reference is further facilitated by a chapter of general information on foreign countries and by a series of tables which show at a glance the conditions under which patents may be obtained from the various governments. The book will be useful to inventors and patent attorneys.

Power Plant Machinery, vol. 1; Mechanism of Steam Engines. By Walter H. James & Myron W. Dole.

Second edition. N. Y., John Wiley & Sons; Lond., Chapman & Hall, 1923. 277 pp., illus., diagrs., 9 x 6 in., cloth. $3.00.

In revising their textbook on the "Mechanism of Steam Engines" the authors decided to expand the work into a general discussion of the principal machines used in a steam power plant; of this work the present book becomes volume one. It is an elementary treatise on the kinematics of reciprocating steam engines and steam turbines, planned for students who take up the subject after a course in the elements of mechanism and before they study the theory and practice of heat engineering. An effort has been made to present the subject so that the beginner will understand the mechanical principles on which the engine operates, with special reference to the valve gear and governing devices, and the various diagrams used to study them. The aim is to treat these questions logically and concisely, yet with sufficient detail to make the principles easily understood.

Practical Railway Maintenance.

By Charles Weiss. N. Y., McGraw-Hill Book Co., 1923. 349 pp., tables, 9 x 6 in., cloth. $3.50.

This book is a concise account of methods and equipment for maintaining railroad track and structures, intended as a text for students and beginners, and also as a reference book for those with experience. The book is divided into four sections. Section one, upon details of track work, discusses gauge, surface, rail elevation, drainage rail renewing, yard track work, wrecks, snows, roadbed, etc. The second section treats of the use and care of track materials and track tools. Section three is devoted to miscellaneous subjects, such as handling men, labor saving devices, reports and records, fire protection, signals, bridges and minor buildings. Section four contains a collection of tables useful to track men.

Radiotelegraphie Et Radiotelephonie A La Portee De Tons.

By G. Malgorn. Paris, Gauthier-Villars et Cie., 1923. 231 pp., illus., diagrs., 9 x 6 in., paper. 10 fr.

Most of the books on radio telegraphy and telephony have been written for those experimenters, amateur or professional, who wish to construct or assemble radio stations. The present writer addresses himself to that larger class of persons who purchase commercial radio sets ready for use, and who are interested only in understanding the principles of the apparatus and in learning how to use it most effectively. The book explains the theory of radio, the functions of the various parts of the receiving set, and supplies practical information on the operation and maintenance of the apparatus.

Railroad Labor Board.

By Joshua Bernhardt. Balt., Johns Hopkins Press, 1923. (Institute for Gov't Research. Service monographs....no. 19). 83 pp., 9 x 6 in., cloth. $1.00.

A concise yet complete account of the origin and purpose of the Railroad Labor Board, of the activities that it has undertaken and the organization available for its work. The book is founded on official statements and reports. A bibliography of publications relating to the administration of the Board is included and also a copy of the laws governing it.

Structure of Atoms.

By Alfred Stock. N. Y., E. P. Dutton & Co., [1923]. 88 pp., diagrs., 9 x 6 in., cloth. $2.50.

In 1919 Professor Stock, of the University of Berlin, delivered to the chemists in one of the large German dye works a series of lectures recent advances in our knowledge of the structure of atoms. These lectures, revised and brought up to date, are here presented in an English translation.

Dr. Stock introduces the subject by a review of the evolution of atomic theories up to the time of the recent period of development. This is followed by an account of the newer work, which is classified by the experimental methods, optical, electrical and radiochemical, which have been used. Chapters on the structure of crystals and the structure of atoms, with a brief bibliography, conclude the book. The author has avoided complicated theoretical physics and mathematics and has given prominence to the experimental point of view.

Theoretical Chemistry.

By Walter Nernst; revised by L. W. Codd. Lond., Macmillan & Co., 1923. (Gift of Macmillan Co., N. Y.). 922 pp., tables, 9 x 6 in., cloth. 28s.

The many friends of this treatise, first published nearly thirty years ago, will welcome this new edition, which is based on the eighth-tenth German edition. Eight years have elapsed since the fourth edition, during which time many important advances have been made in chemistry and physics. The revision has therefore been unusually thorough.

The more important additions deal with the structure of atoms, the applications of X-ray spectroscopy and the determination of molecular dimensions. The chapters on radioactivity and the theory of the solid state have been largely rewritten.

## Past Section Meetings

**Cincinnati.**—May 10, 1923. Subject: "Present Difficulties of Electric Railways." Speaker: L. G. Van Ness, E. E. of The Cincinnati Lawrenceburg & Aurora Electric Railway Co., and Cincinnati, Georgetown and Portsmouth Railroad Co. Attendance 30.

June 14, 1923. Election of the following officers: A. M. Wilson, Chairman; C. G. Eichelberger, Secretary-Treasurer. Dinner was served, followed by a talk on "A Cruise on the Mediterranean." Speaker: Mr. A. J. Conroy. Attendance 35.

**Detroit-Ann Arbor.**—June 19, 1923. Annual Meeting and Picnic. The following officers were elected: E. L. Bailey, Chairman; G. B. McCabe, Vice-Chairman; F. L. Snyder, Secretary-Treasurer. Attendance 30.

**Milwaukee.**—June 20, 1923. This was a joint dinner meeting with the Engineers Society of Milwaukee, after which the following officers were elected: S. H. Mortensen, Chairman; H. L. Smith, Secretary. Attendance 100.

**Rochester.**—May 25, 1923. Election of officers as follows: W. S. Burch, Chairman; F. T. Byrne, Vice-President; E. E. Strong, Secretary-Treasurer. Mr. Vosburch of the Eastman Kodak Company spoke on "House-Wiring." Attendance 60.

**San Francisco.**—May 25, 1923. Illustrated talk on "Some Hydroelectric Developments in Japan." Speaker: J. H. Anderton. Attendance 80.

## Addresses Wanted

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—M. G. Bindler, 2 Margaret St., Derby, Eng.
2.—George G. Chow, c/o S. K. Lau, 351A Weihaiwei Road, Shanghai, China.
3.—Harold B. Clymer, 26 Klein Ave., Trenton, N. J.
4.—R. A. Harman, c/o Tar Heel Mica Co., Plumtree, N. C.
5.—Edwin C. Miller, 968 Morris Ave., Bronx, New York, N. Y.
6.—Cyrus A. Perkins, 139 Dundas St., E., Toronto, Ont., Can.
7.—Richard T. Quaas, 2154 Crotona Ave., New York, N. Y.
8.—Oscar A. Schlesinger, 64 Fairview Ave., Piedmont, Calif.
9.—V. K. Srinivasaiyengar, No. 544-6 Malleswaram, Bangalor, India.
10.—Lester E. Tunison, Pickwick Hotel, 833 So. Grand Ave., Los Angeles, Calif.

# Employment Service

*The Engineering Societies Employment Service is conducted by the national societies of Civil, Mining, Mechanical, and Electrical Engineers as a cooperative bureau available to their membership, and maintained by the joint contributions of the societies and their individual members who are directly benefited.*

*MEN AVAILABLE.—Under this heading brief announcements will be published without charge to the members. These announcements will not be repeated, except upon request received after an interval of three months, during which period names and records will remain in the active files of the bureau. Notice for the JOURNAL should be addressed to* ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City.*** *Such notices will not be acknowledged by personal letter, but if received prior to the 16th of the month will usually appear in the issue of the following month.*

*OPPORTUNITIES.—A bulletin of engineering positions available will be published and will be available to members of the societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance.*

*VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the societies in the financing of the work by nominal contributions. It is believed that a successful service can be developed if these contributions average $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less), three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will, it is hoped, be sufficient to increase and extend the service.*

*REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled, will not be forwarded.*

### MEN AVAILABLE

ELECTRICAL ENGINEER. 6 years' experience hydro-electric power plant operation impulse and reaction wheels. Rotary converters, synchronous converters, synchronous condensers. Willing to go abroad. Can speak Spanish. Age 32. Assoc. A. I. E. E. E-4424

PROFESSOR OF PHYSICS Ph. D. Seven years' excellent record teaching in University; one year's study abroad; five years' in a large industrial research laboratory directing and carrying on research problems, and also connected with executive work; is an excellent teacher, thoroughly interested in his work, well versed in modern theories; has published numerous papers, and is well fitted for organizing and directing research work and departmental affairs. Desires to resume University career. E-4425.

ELECTRICAL ENGINEER. University graduate, member A. I. E. E. with 3 years' experience in railroad electrification, office and field work and 1½ mechanical railroad experience desires position with big contracting firm in connection of power plants or etc., railway engineering. Knowledge of 4 languages, age 27, married. E-4426.

ELECTRICIAN. Graduate E. E. Business School of Correspondence, High School graduate. 12 years' experience as wire-man and in general jobbing as electric light power work, bells, telephone, etc., good tracer and detailer. Desires position with reliable firm, preferably radio or telephone, offering advancement along engineering lines. Age 33, married. Associate A. I. E. E. Other details furnished upon request. E-4427.

SALES ENGINEER wishes to act as manufacturer's agent on a strictly commission basis. Electrical material and equipment preferred. Location, Atlanta. E-4428.

WANTED. Position on construction work or transmission layout and construction. Am technical graduate receiving B. S. in E. E. Married and of American parentage. Westinghouse test floor experience. Salary reasonable. E-4429.

ELECTRICAL AND MECHANICAL. Age, 32, 9 years street railway rolling stock, 6 years hydro-electric power plant operation. Speak Spanish. Available at once. E-4430.

TECHNICAL GRADUATE. Degree from a leading university, age 34, married, no children. Seven years' practical electrical construction experience in large central station. Traveled extensively. Location immaterial. Accustomed to hard work and responsibility. At present in business for myself. Available on short notice. E-4431.

ELECTRICAL ENGINEER 1916. 7 years experience electrician and operating engineer in telegraph power plants, office equipment, testing and maintenance in automatic printing telegraph systems covering all present day systems; including 2 years as instructor in mathematics-electricity and elements of telegraph engineering, Salary $3000. E-4432.

ELECTRICAL DISTRIBUTION ENGINEER. Technical graduate, age 30, married, with G. E. test distribution engineering and central station management experience, wants place with consulting engineering or electrical construction firm. Available on one month's notice. E-4433.

MECHANICAL AND POWER ENGINEER. Technical graduate, eight years' broad experience, machine shop, sugar refinery, industrial and power plant design, construction, heat balance, steam, water, power requirements, utilization, investigation, reports. E-4434.

MOTOR ENGINEER. With eleven years design of motors and motor driven machinery, Universal motors especially. Expert knowledge of motor characteristics and application. Six years in responsible position demonstrating ability to get loyalty and respect of associates. Universal creatine ability. Degrees B. S. and E. E. from prominent University. Age 34,

married. Available on reasonable notice at about $5000. E-4435.

TECHNICAL GRADUATE. With three years' practical experience, consisting of Westinghouse Student Graduate Course, and Public Service work. Have had experience as system operation, as well as maintenance and construction of substations. At present am doing layout and design work on substations. Desire work of supervisory nature in the operating field. Am married, 25 years old and will go anywhere. Require two weeks notice. Can give best of references. E-4436.

ENGINEERING EXECUTIVE Technical graduate, 10 years' experience, valuation, production, cost and job analysis, time study and rate settings, construction, purchasing, engineering and design. Located at present. Wishes to affiliate with growing manufacturing organization or industrial engineer. Age 30. E-4437.

EXECUTIVE Available as general manager, or works manager. Graduate electrical engineer 1903. Industrial engineer and active participant in organization of one of largest manufacturing plants in America, retaining with same high executive position for eight years. Manager of leading Western engineering and construction firm and organizer sales force largest electrical steel and engineering company in Canada. Member of A. I. E. E. At present employed but available reasonable notice. Minimum salary $6000. per annum. E-4438.

GRADUATE ELECTRICAL ENGINEER. Age 35, married. Desires position with power or railway company. Two years testing experience with Westinghouse Company. Had several years' experience on installation and construction work. Supervised operation and maintenance of substation. Also have experience in commercial and distribution work. Would like position as assistant to superintendent or engineer with opportunities for advancement. E-4439.

YOUNG ENGINEER With extensive experience in construction operation and maintenance of electrical end of power properties with their distribution systems. At present connected with New York Engineering Company. Desires position looking to permanent location in service of public utility or of power company in any section, preferably on Pacific coast. Available Oct. 1st. Foreign location considered. E-4440.

ELECTRICAL ENGINEER With experience in design and supervision of manufacture of electrical labor saving devices, desires connection which requires engineering talent and offers good opportunity for growth and advancement. Age 29, married. Available Sept. 1st. E-4441.

ELECTRICAL ENGINEER, five years' experience in distribution and transmission engineering; able to initiate and carry out improvements and economies in existing systems and plans for future development. Have made a special study of economical operation of distribution transformers with special reference to operation on a temperature basis. Wish position leading to executive responsibility in similar fields. Available on 30 days notice. E-4442.

MECHANICAL AND ELECTRICAL ENGINEER, with twenty years' experience desires change. Power house operation maintenance, construction, etc., also street railway, substation, and underground cable experience, and transmission lines up to 110,000 volts. Industrial plant experience also, and willing to handle anything in either line. Available in one weeks notice. E-4443.

ELECTRICAL ENGINEER, five years central station engineering; construction, distribution and meters. Fifteen months General Electric Company, tests. Four years general engineering, layout and cost estimates, transmission lines, substations, large and small motor installations, compressed air pumps, lighting, etc., including supervision of construction. Capable of handling men. Assoc. A. I. E. E. Available at once. E-4444.

ELECTRICAL ENGINEER, B. S. degree 1922, age 24, single, good health and habits. One year in power department of a utility. Desires a position of worth and responsibility, with good future. Employed at present, available on two weeks notice. Location west or middle west preferred. E-4445.

BRAZIL COMMERCIAL ENGINEER, 38, single A. M. E. E. E., A. M. I. Mech. E., Member A. I. E. E., fluent French, German, Portuguese, resident in Brazil since 1911 where he has exceptionally good connections, is willing to act as sole representative of leading contractors, manufacturers, trade financiers and others in negotiations for "big" schemes in which careful preparation and close personal attention on the part of a permanent local representative are indispensable. E-4446.

ELECTRICAL ENGINEER, with fifteen months' practical experience with electric railway, desires position electric or steam railway where opportunity for advancement exists. E-4447.

ENGINEER BUSINESS EXECUTIVE OR PURCHASING AGENT, graduate electrical engineer. Experienced in sales, sales-engineering, purchasing, and executive management. Capable of managing electrical contracting and supply business; new business department of public utilities; purchasing agent-engineer or business executive of industrial companies. Would consider partnership in reliable company. Age 38. Married. Prefer location in eastern or southern United States. Services available on short notice. E-4448.

SALES ENGINEER. Technically trained in mechanical and electrical engineering 16 years' experience in office and field sales work. Available for whole or part time to act as eastern representative. Have own office New England Territory. E-4449.

EXECUTIVE SALES ENGINEER. Briefly stated my technical education and broad business experience has afforded me the opportunity of establishing an excellent sales record having held a position of district manager for seven years and the work has been such as to bring me in close contact with the personnel of consulting engineers, railroad, industrial plants, and central stations covering a territory from NewYork to Baltimore. Wish to join sales organization or control agency for manufacturer of electrical or mechanical apparatus of merit. Location, New York. E-4450.

ENGINEER. Assoc. A. I. E. E., with 25 years' experience in designing, installing and operating practically all classes of machinery, including electrical apparatus, desires position. Speaks Spanish, is a competent executive, having installed and operated machinery and handled all classes of labor, both skilled and unskilled in United States, Mexico and Central America, using native labor in the latter countries. Age, 50, Married, a yellow fever immune, in good health and willing to go to Spanish America. E-4451.

ENGINEER. Graduate E. E. with 5 years' experience including G. E. engineering department, maintenance and testing of high tension meters, and power houses and substation construction. Age 26, married. Available on reasonable notice. E-4452.

ELECTRICAL ENGINEER, 1918 graduate E. E., with G. E. test, 3 years foreign sales with international G. E. Co., and radio experience, married, age 28. Desires position in sales or engineering where personality and executive ability will lead to early advancement. Employed at present, but available at once. Salary expected $250. per month. E-4453.

ELECTRICIAN, with Massachusetts master electricians certificate wishes responsible position with some firm or corporation. I am reliable, steady and industrious. Experienced in all branches of work. I am 25 years of age, and have 10 years' experience. Am a graduate of the Wentworth Institute of Applied Electricity, 3 years 1 year course in steam power plant operation of Wentworth Institute. Graduate from Mullane's Engineering School and from other firms. Open for position. E-4454.

GRADUATE MECHANICAL ENGINEER. Assoc. A. I. E. E., licensed engineer N. Y. State. Has had 25 years' experience in shop and office work, for the past 17 years with U. S. Navy, 8 years as supervisor responsible for the preparation of plans and installation of lighting, power and signaling systems, switchboards, batteries and development of special appliances used aboard ships. Owing to the present uncertainty of permanancy of navy yard work will consider position as sales engineer with manufacturers of ship's electrical appliances, batteries, instruments. In the vicinity of N. Y. City. E-4455.

ELECTRICAL ENGINEER, college graduate, age 26, married. Experienced in metropolitan railway systems, out door and indoor substations, high-tension line design, power surveys, production and time study. Familiar with modern production methods and cost accountancy. Desires change to position of responsibility and future opportunities. E-4456.

GRADUATE ELECTRICAL ENGINEER. with laboratory and teaching experience desires position. Training consists of tests and research at Bureau of Standards, test floor, and responsible charge of laboratory with motor manufacturing concern, and several years teaching at large eastern school. Am open for immediate engagement. E-4457.

ELECTRICAL motor designer and industrial application engineer, desires opportunity to locate in or near Michigan. Can show excellent record, specializing on induction and synchronous motor design and application. Also two years' teaching experience. At present in charge of experimental division of large manufacturing company. Salary $3000. E-4458.

ELECTRICAL ENGINEER, age 30, college graduate Westinghouse students training course, engineering and sales experience is offering his service to American firms engaged in export trade in U. S. or abroad in sales or engineering capacity. E-4459.

ELECTRICAL ENGINEERING GRADUATE. Assoc. A. I. E. E., who has had twenty months' experience in G. E. test and a years' experience in the engineering department of a public utility and manufacturing company in connection with switchboards, indoor and outdoor substations and transmission, desires position offering possibilities of advancement. E-4460.

ELECTRICAL ENGINEER '17. Available immediately for public service company, industrial concern, or consulting engineering firm. Westinghouse test floor and engineering department, automatic industrial applications in steel mill, construction, operation, teaching engineering. References if desired. E-4461.

AM A 1919 GRADUATE of the E. E. Course at Cooper Union Institute, degree of B. S., age 26. Have had 2 years of D. C. Machinery testing, and have five years' experience as electrician on electric light and power installation. Would like position with electric light power or mining concern. Main consideration chance for experience. Location immaterial. E-4462.

WAS GRADUATE FROM UNIVERSITY and completed test course of large electrical manufacturer. Ten years office and field sales in central station equipment and industrial plant apparatus and process requirements. Seek change that will allow close working with individual or participation in smaller company. However if traveling and commission or bonus can be earned would start at $3600. per year and expenses. E-4463.

GRADUATE ELECTRICAL ENGINEER, having teaching and practical experience, desires position of associate professor of E. E. Applicant is 35 years of age, married and prefers middle west. No consideration will be given under $4000. E-4464.

ELECTRICAL ENGINEER, age 23, single, 1922 graduate. For the past year has been engaged in illuminating engineering. Desires to become associated with a consulting firm, or with a large operating company. Only positions with possibilities and chance for advancement will be considered. Employed at present but available on short notice, New York, New Jersey, or Penna. preferred. E-4465.

GRADUATE with B. S. degrees in electrical and agricultural engineering from prominent state university of middle west, desires position with organization where this combination training would be of mutual benefit and where opportunities for advancement are limited only by applicants ability to measure up to them. Three years' teaching experience. Two years' practical experience in electrical chemical and agricultural industries. Experience in handling men. Age 28 years, married, family. Location not first consideration. Available on months notice. E-4466.

FIELD ENGINEER, thoroughly experienced in estimating, design, supervision and erection of heating, ventilating, plumbing, power piping and automatic sprinkler systems; experience on large projects of the better kind. Have just completed equipment in 24 story office building in large eastern city. Location immaterial, although eastern U. S. preferred. Permanent connection desired, with possibilities. Assoc. A. I. E. E. & A. S. H. & V. E. Still employed, but desires change. E-4467.

# MEMBERSHIP — Applications, Elections, Transfers, Etc.

**ASSOCIATES ELECTED AUGUST 2, 1923**

ALLEN, FREDERICK JAMES, Operating Engineer, Power House, Pacific Power & Light Co., Naches, Wash.

ANDERSON, J. HARVEY, Electrical Foreman, Newberry Electric Corp., Los Angeles; res., Hollywood, Calif.

BAILEY, ROBERT PICKUP, Engineer, General Electric Co., 510 Dwight Bldg., Kansas City, Mo.

BASSETT, CYRUS W., Designing Engineer, Elevator Supplies Co., Inc., Hoboken, N. J.

BINFORD, JOHN TURNER, Engg. Assistant, The Chesapeake & Potomac Telephone Co., 725 13th St., N. W., Washington, D. C.

BLAKE, DAVID KELLER, Lighting Engineering Dept., General Electric Co., Schenectady, N. Y.

*BLAKESLEE, EDWIN MITCHELL, Student, Stanford University, Stanford University, Calif.

BOWLING, NICHOLAS, Electrical Engineer, Westinghouse Elec. & Mfg. Co., 12 Farnsworth St., Boston; res., Lawrence, Mass.

BOYLE, WILLIAM EDWARD, Engineer, Transmission & Distribution Dept., United Electric Light & Power Co., 130 E. 15th St., New York, N. Y.

BROWER, RUFUS FRANK, Foreman, Testing Dept., New York Edison Co., 92 Vandam St., New York, N. Y.

BRUNNER, ALBERT F., Foreman Electric Constr., Brooklyn Edison Co., 360 Pearl St., Brooklyn, N. Y.

BULLEN, HARRY B., Superintendent, Southern Div., Edison Electric Illuminating Co., 39 Boylston St., Boston; res., Dedham, Mass.

CAREY, PATRICK THADDEUS, Engineer and Superintendent, China Electric Co., Ltd., Piao Chang-Ku, Cha-dao, Peking, China.

CARLETON, FRED C., Local Manager, Northwestern Electric Co., Camas, Wash.

CARLSEN, FRED HARRY, Field Engineer, Public Service Electric Co., Hackensack, N. J.

CAULFIELD, JAMES S., Technical Assistant, Inside Plant Bureau, Brooklyn Edison Co., 360 Pearl St., Brooklyn, N. Y.

CLARKE, CAUDELLE GEORGE TRACY, Hydro-Electric Operator, Cero De Pasco Copper Corp., Oroya, Peru, S. A.

CLEMONS, DALE ROGER, Instructor in Radio, Dodge's Institute, Valparaiso, Ind.

COLLISON, GEORGE CHESTER, Proprietor, Witherbee Battery Co., 1410 Eye St., N. W., Washington, D. C.

COLONY, MARTIN PRATT, Line Estimator, The Milwaukee Electric Railway & Light Co., Milwaukee, Wis.

COX, PAUL EDWARD, Draftsman, Georgia Railway & Power Co., 211 Decatur St., Atlanta, Ga.

DE GRAAFF, ANTONIUS, Chemical Engineer, Philips Glow Lamp Works, Ltd., Eindhoven, Holland.

DIEFENDERFER, JOHN HALFORD, Chief Load Dispatcher, East Penn Electric Co., 2nd & Market Sts., Pottsville, Pa.

DOBBINS, WALTER EUGENE, JR., Part Owner & Manager, Radio Dept., Capital Electric Co., 63 Peachtree St., Atlanta, Ga.

DOHL, ALFRED PHILIP, Supervisor & Estimator, Electricity Construction, E. A. Koeneman Electric Co., 214 Coll. Ave., East St. Louis, Ill.

DONAHUE, JOHN CHARLES, Substation Operator, City of Tacoma, 11th & Sitcum Ave., Tacoma, Wash.

DOWNEY, JOHN CHARLES, Foreman, Hawera County Electric Co., Hawera, N. Z.

ELLIS, JAMES LAWTON, Jr., Asst. Professor of Electrical Engg., Georgia School of Technology, Atlanta, Ga; for mail, Allendale, S. C.

FERGUSON, LAWRENCE WHETFIELD, Electrician, Killarney Coal Co., Killarney, W. Va.

FLESHLER, AARON D., Bureau of Equipment and Operation, Transit Commission, 49 Lafayette St., New York, N. Y.

FORTIES, RICHARD WRIGHT, Maintenance Work, Canadian General Electric Co., Ltd., Queenston, Ont., Can.

*FUOG, ARNOLD THEO., Cost Engineer, Harvey Electric Co., 2000 Southport Ave., Chicago, Ill.

GADKARY, SADASHIV ATMARAM, Student Engineer, General Electric Co., Inc., Schenectady, N. Y.

GAMBLE, LESTER RAYMOND, Distribution Engineer, Washington Water Power Co., W-825 Trent Ave., Spokane, Wash.

GARBETT, JAMES HAROLD, Electrician, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Turtle Creek, Pa.

GARCIA, GUILLERMO, Superintendent, Wiring & Lighting Dept., Empresa Electrica de Guatemala, A. Foreign Power & Light Co., 9 Calle Poniante & 2a Ave., Guatemala, C. A.

GERSCH, ADOLPH EDWARD, Draftsman, Commonwealth Edison Co., 700 Edison Bldg., Chicago, Ill.

GRAHAM, VIRGIL N., Laboratory Assistant, Stromberg-Carlson Telegraph Mfg. Co., 1050 University Ave., Rochester, N. Y.

GREENLEE, ROBERT P., Central Station Operator, Commonwealth Edison Co., 24th & Quarry Sts., Chicago, Ill.

HARRELL, WALTER E., Underground, Clerk, Bureau of Power & Light, City of Los Angeles, 120 E. 4th St., Los Angeles, Calif.

HAYS, SAMUEL L., Mechanical Supt., The Rapid Electrotype Co., McMeeken & Race Sts., Cincinnati, Ohio.

HENRY, EDWARD, In Charge of Maintenance & Distribution, Electricity Dept., Christchurch City Council, Christchurch, N. Z.

HURSH, JOHN I., Electrical Engineer, Sargent & Lundy, Edison Bldg., Chicago, Ill.

JOHNSTONE, WINTERS 'S., Construction Engineer, Erie Railroad, Hornell Shops, Hornell, N. Y.

JONES, LELAND, Electrician, Phoenix Utility Co., Camp No. 5, Grace, Idaho.

JUHNKE, ELMER C., The United Gas Improvement Contracting Co., Broad & Arch Sts., Philadelphia, Pa.

KERR, STEWART, Division Maintenance Engineer's Office, New York Telephone Co., 227 E. 30th St., New York; res., Bronxville, N. Y.

KETTENRING, LOUIS R., Electrical Engineer, Electric Service Dept., University of Washington, Seattle, Wash.

*KIST, CARL FREDERICK, Jr., Draftsman, The E. W. Clark & Co., Huntington Bank Bldg., Columbus, Ohio.

LAPHAM, EDWARD AMILE, Sales Engineer, Morganite Brush Co., 519 W. 38th St., New York, N. Y.

LEIGHTON, HAROLD D., Electrician, Minnesota Electric Light & Power Co., Cushing, Okla.

LEINER, WILLIAM JAMES, Instructor, Machine Switching Telephony, Southern California Telephone Co., Los Angeles, Calif.

LEONARD, W. D., Manager, City Water, Light & Gas Commission, Fort Atkinson, Ark.

LEVISON, EMANUEL, Vice-President & Chief Engineer, The Industrial Electric Co., 5230 St. Clair Ave., Cleveland, Ohio.

LEVY, DAVID H., Superintendent of Construction, E. W. Tompkins Co., 27 Grand St., Albany; for mail, Central Islip, N. Y.

LINDLOF, FREDERICK ADOLPH, Maintenance Supervisor Plant Dept., Western Union Telegraph Co., 610 S. Spring St., Los Angeles, Calif.

LINTNER, GARFIELD U., Jr., Aerological Meteorologist, U. S. Marine Corps, Marine Flying Field, Quantico, W. Va.

LITTLE, GEORGE FRANKENFIELD, Chief Electrician U. S. Navy, U. S. S. Bainbridge, New York, N. Y.

LUNDELL, TORSTEN ADIL, Switchboard Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

MATTHEWS, CLIFFORD HARRY, Foreman, Meter Dept., Toledo & Western Railroad Co., Sylvania; res., Toledo, Ohio.

MATTHEWS, WILLIAM R., Asst., Electrical Engineer, Washington Water Power Co., Spokane, Wash.

MELVILLE, JAMES H., Foreman, Substation & Transformer Maintenance Div., Dallas Power & Light Co., Park & Marilla Sts., Dallas, Tex.

METZ, CARL J., Division Supervisor of Equipment, Ohio Bell Telephone Co., Akron, Ohio.

MILLS, GEORGE EDWARD, Superintendent of Installation, Signal Systems, Ltd., Wellington St., E., Toronto, Ont., Can.

MITCHELL, HENRY FREDERICK, Electrical Foreman, San Joaquin Light & Power Corp., Fresno, Calif.

MORGAN, DANIEL TENNYSON, Chief Electrician, Beech Bottom Power Co., Power, W. Va.

ONO, HIROSHI, Electric Engineer, Mitsubishi Electric Works, Kobe, Japan.

PARKER, WASHINGTON W., Testing Engineer, Commonwealth Edison Co., Chicago, Ill.

*PARKS, MARVIN B., Wireman, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

PARKS, MURRILL DOUGLAS, District Superintendent, Western Public Service Co., Scottsbluff, Nebr.

PETZ, ALFRED H., Experimental Work, National District Telegraph Co., 68-76 King St., New York, N. Y.

POTTER, E. ESTABROOK, Installing Dept., Western Electric Co., Inc., 401 Hudson St., New York; res., Brooklyn, N. Y.

REID, HENRY LAMAR, Manager Radio Dept., Capital Electric Co., 63 Peachtree St., Atlanta, Ga.

ROBINSON, WILLIAM DWIGHT, Chief Electrician, Modoc Lumber Co., Aspgrove, Ore.

RUSH, ELOYD MASON, Receiving Engineer, Radio Corp. of America, Marshall, Calif.

SCHAETZLE, HAROLD JAY, Engg. Assistant, Bell Telephone Co. of Penna., 261 N. Broad St., Philadelphia, Pa.

SCHROETTER, EDWIN ODYS, Electrical Engineer, Larkin Co., Inc., Buffalo, N. Y.

SCHWARTZ, DAVID L., res., 207 W. 118th St., New York, N. Y.

SCHWEBEL, AUGUST XAVIER, Electrical Engineer, The Atlas Electric & Manufacturing Co., Middletown, Ohio.

SCOTT, ROBERT CLYDE, Senior Draftsman, Union Gas & Electric Co., Front & Rose Sts., Cincinnati, Ohio.

SINNOTT, CHARLES EDMUND, Chief Electrician, American Can Co., Boston & Hudson Sts., Baltimore, Md.

SMITH, JOSEPH J., Asst. General Foreman, Brooklyn Edison Co., 360 Pearl St., Brooklyn, N. Y.

SMITH, PLATT H., Inspector, Electric Construction, Brooklyn Edison Co., 561 Grand Ave., Brooklyn, N. Y.

*STAMPER, FURMAN HARRISON, Technical Assistant, Brooklyn Edison Co., 360 Pearl St., Brooklyn, N. Y.

STEINAU, JOHN M., 18 Brookdale Ave., New Rochelle, N. Y.

STEPHENS, LIONEL COUNSELL, Clerk of Works, Municipal Electricity Dept., City Council, Armagh St., Christchurch, N. Z.

STOLL, ALBERT F., President, Russell & Stoll Co., 17-27 Vandervater St., New York, N. Y.; res., East Orange, N. J.

TRUEMAN, MARK CECIL, Apprentice, Canadian Westinghouse Co., Hamilton, Ont., Can.

TYMON, CHARLES P., Switchboard Instrument & Control Work, The United Gas & Improvement Co., Bethlehem, Pa.; res., New York, N. Y.

UNGERER, HOWARD LAWRENCE, Draughtsman, Elevator Supplies Co., Inc., 1515 Willow Ave., Hoboken, N. J.; res., New York, N. Y.

VALLAS, MINER HOWARD, Instructor in Electrical Engineering, Tulane University, New Orleans, La.

WEIDNER, EARL W., Electric Supply & Maintenance Co., 224 North 10th St., Reading, Pa.

WIESNER, FRED K., c/o C. O. Bergman, 479 West 152nd St., New York, N. Y.

WILSON, WILLIAM S., Electrician, Hudson Coal Co., 60 Boston Hill, Luzern Co., Plymouth, Pa.

WOLFF, LOUIS, Chief Electrician, Brunswick-Balke Collender Co., Muskegon, Mich.

ZARTH, WILLIAM AUGUST FREDERICK, Chief Electrician, Stamford Rolling Mills Co., Springdale, Conn.

Total 96.

*Formerly Enrolled Students.

### ASSOCIATES REELECTED AUGUST 2, 1923

BLACK, DOUGLAS C., Engineer, J. G. White Engineering Corp., 43 Exchange Place, New York, N. Y.

MAYER, FREDERICK HERMAN, Designer, Southern California Edison Co., 3rd & Broadway, Los Angeles, Calif.

### ASSOCIATE REINSTATED AUGUST 2, 1923

BIELE, HARRY MARTIN, Chief of Telegraph Printer Dept., The Associated Press, 51 Chambers St., New York, N. Y.

### MEMBERS ELECTED AUGUST 2, 1923

ANDERSON, ARTHUR NATHANIEL, Asst. General Superintendent, Vanadium Corp. of America, Bridgeville, Pa.

BELLOWS, GUY, Field Engineer, Railway Engg. Dept., General Electric Co., Caixa Postal 547, Sao Paulo, Brazil, S. A.

COOKE, BENNETT WELLINGTON, President, Coyne Trade & Engineering School, 1300 W. Harrison St., Chicago, Ill.

FOX, ARTHUR WARD, Vice-President & General Manager, Johns-Pratt Co., Hartford, Conn.

KENYON, LOT AMOS, Engineer, Electrical Distribution, Montreal Light, Heat & Power Consolidated, 83 Craig St., W., Montreal, Que., Can.

MARSHALL, ERNEST, Electrical Engineer, Great Northern Railway, 816 Great Northern Bldg., St. Paul, Minn.

PETERMAN, WILLIAM CLINTON, Member, Engineering Staff, Western Union Telegraph Co., 195 Broadway, New York. N. Y.

TUCK, DAVIS HENRY, Electrical Engineer, Holophane Glass Co., Inc., 342 Madison Ave., New York, N. Y.

### FELLOW ELECTED, JUNE 27, 1923

GUPTA, BIRENDRA CHANDRA, Professor, Electrical Engineering, Bengal Engineering College, Calcutta University, India.

### TRANSFERRED TO GRADE OF FELLOW AUGUST 2, 1923

BOZELL, HAROLD V., Editor, *Electrical World*, New York, N. Y.

MANSON, GEORGE K., Chief Engineer, New England Telephone & Telegraph Co., Boston, Mass.

WOODROW, HARRY R., Assistant Electrical Engineer, Brooklyn Edison Co., Brooklyn, N. Y.

### TRANSFERRED TO GRADE OF MEMBER AUGUST 2, 1923

DENNISON, BOYD C., Associate Professor of Electrical Engineering, Carnegie Institute of Technology, Pittsburgh, Pa.

FERNALD, JOHN M., Engineer, Cutler-Hammer Manufacturing Co., Boston, Mass.

HEUSER, JOHN U., Branch Manager, Cutler-Hammer Manufacturing Co., Chicago, Ill.

JALONACK, HAROLD M., Transformer, Regulator & Lightning Arrester Specialist, General Electric Co., New York, N. Y.

NASH, E. J., Acting General Manager, Butte Electric Railway Co., Butte, Mont.

PEARCE, WALTER R., Chief Engineer, New Brunswick Telephone Co., Ltd., St. John, N. B.

RICHMOND, HAROLD B., Secretary, General Radio Co., Cambridge, Mass.

SILLS, GEORGE F., Branch Manager, English Electric Co. Ltd., Manchester, England.

SPLITSTONE, EDWARD L., Emerson Electric Mfg. Co., St. Louis, Mo.

### RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held July 30, 1923, recommended the following members of the Institute for transfer to the grades of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

#### To Grade of Fellow

FULLER, LEONARD F., Radio Engineering Dept., General Electric Co., Schenectady, N. Y.

LANGLEY, GORDON R., Switchboard Dept., Canadian General Electric Co., Peterboro, Ont.

#### To Grade of Member

HELLENTHAL, JOSEPH, Supt. of Transmission, Puget Sound Power & Light Co., Seattle, Wash.

KRANZ, HERMANN E., Development Engineer, Western Electric Co., Hawthorne Station, Chicago, Ill.

MELVIN, H. L., Electrical Engineer, Washington Water Power Co., Spokane, Wash.

MILNOR, JOSEPH W., Research Engineer, Western Union Telegraph Co., New York, N. Y.

MONTGOMERY, THEODORE D., Eastern District Manager, Cutler-Hammer Mfg. Co., New York, N. Y.

SHACKLETON, S. P., Engineer, American Telephone & Telegraph Co., New York, N. Y.

TIKHONOVITCH, BENEDICT, Electrical Engineer, Engineering Dept., New York Edison Co., New York, N. Y.

YENSEN, TRYGVE D., Research Engineer, Westinghouse Research Laboratory, W. E. & M. Co., East Pittsburgh, Pa.

### APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before September 30, 1923.

Abraham, Y., G. & W. Electric Specialties Co., Chicago, Ill.

Ames, I. M.; 504 S. 11th St., Newark, N. J.

Arceo, A., The Mexican Light & Power Co., Ltd., Mexico City, Mex.

*Bailey, R. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Batsford, H. E., Utica Gas & Elec. Co., Utica, N. Y.
Beckman, J. S., Bell Tel. Co. of Pa., Philadelphia, Pa.
*Beers, R. F., Western Electric Co., New York, N. Y.
Boelsterli, A. A., Electric Bond & Share Co., New York, N. Y.
Brown W. A. R., Radio Corporation of America., Port Jefferson, N. Y.
*Burnham, G. L., Wisconsin Telephone Co., Milwaukee, Wis.
Cassin, W. D., Westinghouse Elec. & Mfg. Co., Philadelphia, Pa.
Clinton, J. F., U. S. Shipping Board, New York, N. Y.
Collins, W. O., Western Electric Co., Philadelphia, Pa.
Crane, E. B., The Penna-Ohio Power & Light Co., Youngstown, Ohio
Crowne, I. H., Brooklyn Edison Co., Brooklyn, N. Y.
Cunningham, F., A. C. Burke & Co., Toronto, Ont.
Davis, J. C., Kansas City Power & Light Co., Kansas City, Mo.
Doe, A. N., Rhode Island State College, Kingston, R. I.
Eckstein, F., New Orleans Public Service, Inc., New Orleans, La.
Evans, F. B., Jr., Bell Tel. Co. of Pa., Philadelphia, Pa.
Fleming, J. M., Westinghouse Elec. & Mfg. Co., Mansfield, Ohio
*Goetschius, W. L., Stony Point, N. Y.
Hallock, H. A., Western Electric Co., Inc., Dayton, Ohio
Halfin, W., Brooklyn-Manhattan Transit Co., Brooklyn, N. Y.
Hand, R. W., Bell Telephone Co., Philadelphia, Pa.
Henneberry, P. Y., Western Electric Co., Philadelphia, Pa.
Jensen, N. P. R., Western Electric Co., New York, N. Y.
Kahow, E. M., Bell Tel. Co. of Pa., Philadelphia, Pa.
Keohane, J. J., Weston Instrument Co., Newark, N. J.
*Kneale, C. K., Philadelphia Electric Co., Philadelphia, Pa.
Lamb, F. B., West Virginia Engg. Co., Charleston, W. Va.
MacGregor, J. R., Bell Tel. Co. of Pa., Philadelphia, Pa.
*Mack, L. F., Western Electric Co., Philadelphia, Pa.
Maskell, J. W., 4723 N. 13th st., Philadelphia, Pa.
Matsushita, J. S., 102 West 123rd St., New York, N. Y.
McDonough, T. J., Western Electric Co., New York, N. Y.
Merlin, H. R., Interborough Rapid Transit Co., New York, N. Y.
Merrick, C. S., Western Electric Co., Inc., Philadelphia, Pa.
Metchear, C. R., (Member), Watertown Electric Co., Watertown, Mass.
Midulla, B., 158 West 65th St., New York, N. Y.
Mitchell, O. L., Hydro-Electric Power Comm., Toronto, Ont.
Morgan, T. H., Great Western Power Co., San Francisco, Calif.
Morris, G., Crovo Electric Co., New York, N. Y.
Muller, R. F. A., (Fellow), 1474 Columbia Road, Washington D. C.
Musser, H. P., West Virginia Engineering Co., Charleston, W. Va.
Naef, O., Scintilla Magneto Co., New York, N. Y.
Naugle, J. F., D. P. Robinson & Co., Inc., New York, N. Y.
O'Leary, P. J., Western Union Telegraph Co., Bay Roberts, Newfoundland
Orley, G. E., Stone & Webster, Inc., Boston, Mass.
Palmquist, W. N., Northern States Power Co., St. Paul, Minn.
Peterson, A., 503 W. 121 St., New York, N. Y.
Preston, L. H., Portland Ry., Lt. & Pr. Co., Portland, Ore.
Robinson, R. W., Philadelphia Electric Co., Philadelphia, Pa.
Rosier, J. P., Hudson Coal Co., Wolf Summit, W. Va.
Smith, W. R., Western Electric Co., Chicago, Ill.
Sredenschek, W. A., General Electric Co., Schenectady, N. Y.
Stertman, E. J., Imperial Refineries, Ltd., Montreal, Quebec, Can.
Story, L. R., Home Gas & Electric Co., Greeley, Colo.
Thorell, D., Westinghouse Elec. & Mfg. Co., Chicago, Ill.
Thorp, L. J., Western Electric Co., Chicago, Ill.
Thvedt, C. B. M., United Elec. Lt. & Pr. Co., New York, N. Y.
Ulbrich, M. A., N. Y. & Queens Elec. Lt. & Pr. Co., Long Island City, N. Y.
Wayts, M. E., International Rubber Co., Anderson, Ind.
Weinreb, O., Acme-International X-Ray Co., Chicago, Ill.
Wright, J. L., Pennsylvania Pr. & Lt. Co., Hazleton, Pa.
Wyatt, H. E., Western Union Telegraph Co., Trinity Bay, Newfoundland
Zimmerer, C. W., Crocker-Wheeler Co., Ampere, N. J.
Total 67

**Foreign**

Durham, G., Wellington City Corp., Wellington, N. Z.
Fletcher, C. N., Messrs. Edward-G-Herbert Ltd., Manchester, England.
Flood, J. P., Quarter Master Corps., Schofield Barracks, T. H.
Jewsbury, W., Newcastle City Council, Newcastle, N. S. W., Aus.
Karani, M. F., The Gwalior Cement Co., Ltd., Banmore, India.
Payne, L. S., Public Works Dept., Wellington, N. Z.
Plaza, H. P., Chilean State Railways, Chile, S. A.
Walker, H. B., Central Electric Power Board, Hamilton, Waikato, N. Z.
Wilson, W. A., Commonwealth Steel Products Co., Ltd., Waratah, N. S. W., Aus.
Total 9

**STUDENTS ENROLLED AUGUST 2, 1923**

17342 Eacker, Earl H., Mass. Institute of Tech.
17343 Kwei, Ming-Sin, Cornell University
17344 Clement, Neal F., Rensselaer Polytechnic Institute
17345 Tifft, Wayne I., Rensselaer Polytechnic Institute
17346 Chamberlain, Barnwell R., Rensselaer Polytechnic Institute
17347 Lowe, H. F., Purdue University
17348 Obenchain, Edgar T., Purdue University
17349 Lederer, Milton, Pennsylvania State College
17350 Brockington, Harry G., Mass. Institute of Technology
17351 Kaul, Richard J., Stevens Institute of Technology
17352 Nash, Harold R., University of Detroit
17353 Gafford, Burns N., University of Texas
17354 Zink, Hal H., University of Illinois
17355 Gilman, William C., Mass. Institute of Technology
17356 Bellezza, Russell G., Mass. Institute of Technology
17357 Plaus, Robert A., University of Nevada
17358 Townsend, Joseph H., Mass. Institute of Technology
17359 Caldwell, Samuel H., Mass. Institute of Technology
17360 Carlton, Edward W., Mass. Institute of Technology
17361 MacLean, James B., Mass. Institute of Technology
17362 Wilmot, Francis E., Mass. Institute of Technology
17363 Meyerand, Russell G., Mass. Institute of Technology
Total 22

# Officers A. I. E. E. 1923-1924

**PRESIDENT**
(Term expires July 31, 1924)
HARRIS J. RYAN

**JUNIOR PAST-PRESIDENTS**
(Term expires July 31, 1924)
WILLIAM McCLELLAN
(Term expires July 31, 1925)
FRANK B. JEWETT

**VICE-PRESIDENTS**
(Terms expire July 31, 1924)
W. I. SLICHTER (District No. 3)
R. F. SCHUCHARDT (District No. 5)
H. T. PLUMB (District No. 9)
G. FACCIOLI (District No. 1)
H. W. EALES (District No. 7)
(Terms expire July 31, 1925)
J. E. MACDONALD (District No. 8)
HERBERT S. SANDS (District No. 6)
S.E.M. HENDERSON (District No.10)
H. E. BUSSEY (District No. 4)
WILLIAM F. JAMES (District No. 2)

**MANAGERS**
(Terms expire July 31, 1924)
HAROLD B. SMITH
JAMES F. LINCOLN
E. B. CRAFT
(Terms expire July 31, 1925)
R. B. WILLIAMSON
A. G. PIERCE
HARLAN A. PRATT
(Terms expire July 31, 1926)
H. M. HOBART
ERNEST LUNN
G. L. KNIGHT
(Terms expire July 31, 1927)
WILLIAM M. McCONAHEY
W. K. VANDERPOEL
H. P. CHARLESWORTH

**TREASURER** **SECRETARY**
(Terms expire July 31, 1924)
GEORGE A. HAMILTON
F. L. HUTCHINSON

**HONORARY SECRETARY**
RALPH W. POPE

**GENERAL COUNSEL**
PARKER & AARON
30 Broad Street, New York.

**PAST-PRESIDENTS—1884-1923**

*Norvin Green, 1884-5-6.
*Franklin L. Pope, 1886-7.
T. Commerford Martin, 1887-8.
Edward Weston, 1888-9.
Elihu Thomson, 1889-90
*William A. Anthony, 1890-91.
*Alexander Graham Bell, 1891-2.
Frank Julian Sprague, 1892-3.
*Edwin J. Houston, 1893-4-5.
*Louis Duncan, 1895-6-7.
*Francis Bacon Crocker, 1897-8.
A. E. Kennelly, 1898-1900.
Carl Hering, 1900-1.
Charles P. Steinmetz, 1901-2.
Charles F. Scott, 1902-3.
Bion J. Arnold, 1903-4.
John W. Lieb, 1904-5.
*Schuyler Skaats Wheeler, 1905-6.
*Samuel Sheldon, 1906-7.
*Henry G. Stott, 1907-8.
Louis A. Ferguson, 1908-9.
Lewis B. Stillwell, 1909-10.
Dugald C. Jackson, 1910-11.
Gano Dunn, 1911-12.
Ralph D. Mershon, 1912-13.
C. O. Mailloux, 1913-14.
Paul M. Lincoln, 1914-15.
John J. Carty, 1915-16.
H. W. Buck, 1916-17.
E. W. Rice, Jr., 1917-18.
Comfort A. Adams, 1918-19.
Calvert Townley, 1919-20.
A. W. Berresford, 1920-21.
William McClellan, 1921-22.
Frank B. Jewett, 1922-23.

*Deceased.

**LOCAL HONORARY SECRETARIES**

Carrol M. Mauseau, Caixa Postal No. 571, Rio de Janeiro, Brazil, S. A.
Charles le Maistre, 28 Victoria St., London, S. W., England.
A. S. Garfield, 45 Bd. Beausejour, Paris 16 E, France.
H. P. Gibbs, Tata Sons Ltd., Navsari Building, Fort Bombay, India.
Guido Semenza, 39 Via Monte Napoleone, Milan, Italy.
Lawrence Birks, Public Works Department, Wellington, New Zealand
W. Elsdon-Dew, P. O. Box 4563, Johannesburg, Transvaal, Africa.

# A. I. E. E. Committees

## GENERAL STANDING COMMITTEES

**EXECUTIVE COMMITTEE**

Harris J. Ryan, Chairman, Stanford University, Calif.
Frank B. Jewett, Vice-Chairman
E. B. Craft, G. L. Knight, William McClellan,
George A. Hamilton, W. I. Slichter.

**FINANCE COMMITTEE**

G. L. Knight, Chairman, 360 Pearl Street, Brooklyn, N. Y.
W. I. Slichter, W. K. Vanderpoel.

**MEETINGS AND PAPERS COMMITTEE**

L. W. W. Morrow, Chairman, *Electrical World*, 10th Ave. & 36th St., New York, N. Y.
E. E. F. Creighton, E. B. Meyer, John Mills
J. E. Macdonald, D. W. Roper.
Chairman of Committee on Coordination of Institute Activities.
Chairmen of Technical Committees.
Chairmen of Sections.

**PUBLICATION COMMITTEE**

Donald McNicol, Chairman, 132 Union Road, Roselle Park, N. J.
F. L. Hutchinson, E. B. Meyer, L. W. W. Morrow,
L. F. Morehouse.

**COMMITTEE ON COORDINATION OF INSTITUTE ACTIVITIES**

W. I. Slichter, Chairman, Columbia University, New York, N. Y.
F. L. Hutchinson, G. L. Knight, L. W W. Morrow.
Donald McNicol,

**BOARD OF EXAMINERS**

H. H. Norris, Chairman, 211 Lorraine Avenue, Upper Montclair, N. J.
E. H. Everit, G. L. Knight, J. H. Morecroft,
F. M. Farmer, F. V. Magalhaes, N. L. Pollard.
Erich Hausmann, Donald McNicol,

**SECTIONS COMMITTEE**

A. W. Berresford, Chairman, 303 Hotel Astor, Milwaukee, Wis.
C. E. Magnusson, Vice-Chairman.
H. H. Henline, Herbert S. Sands, Harold B. Smith.
Chairmen of all Sections.

**COMMITTEE ON STUDENT BRANCHES**

C. E. Magnusson, Chairman, University of Washington, Seattle, Wash.
F. S. Dellenbaugh, Jr., C. Francis Harding, Harold B. Smith.
Charles F. Scott,

**MEMBERSHIP COMMITTEE**

M. E. Skinner, Chairman, Duquesne Light Co., Pittsburgh, Pa.
C. E. Baker, C. E. Fleager, H. T. Plumb.
E. E. Dorting, S. E. M. Henderson, J. F. Warwick,
John M. Drabelle, G. A. Kositzky, J. L. Woodress.
Chairmen of local membership committees.

**HEADQUARTERS COMMITTEE**

E. B. Craft, Chairman, 463 West Street, New York, N. Y.
F. L. Hutchinson, G. L. Knight.

**LAW COMMITTEE**

H. H. Barnes, Jr., Chairman, General Electric Co., 120 Broadway, New York, N. Y.
G. E. Folk, P. Junkersfeld, Charles A. Terry.
R. F. Schuchardt,

**PUBLIC POLICY COMMITTEE**

H. W. Buck, Chairman, 49 Wall Street, New York, N. Y.
A. W. Berresford,. F. B. Jewett, William McClellan,
Gano Dunn, John W. Lieb, Calvert Townley.

**COMMITTEE ON CODE OF PRINCIPLES OF PROFESSIONAL CONDUCT**

John W. Lieb, Chairman, 124 E. 15th Street, New York, N. Y.
Comfort A. Adams, G. Faccioli, H. S. Wynkoop,
A. H. Babcock, George F. Sever, C. E. Skinner.

**SAFETY CODES COMMITTEE**

H. B. Gear, Chairman, 72 West Adams St., Chicago, Ill.
H. A. Barre, L. C. Ilsley, Alexander Marks,
H. H. Cochrane, M. G. Lloyd, R. W. E. Moore,
E. E. F. Creighton, Ernest Lunn, H. R. Sargent,
W. B. Hartshorne, Wills Maclachlan H. S. Warren.

**STANDARDS COMMITTEE**

**Executive Committee**

H. S. Osborne, Chairman, A. T. & T. Co., 195 Broadway, New York, N. Y.
W. A. Del Mar, A. M. MacCutcheon, F. L. Rhodes,
H. M. Hobart, J. Franklin Meyer, L. T. Robinson,
G. L. Knight, F. D. Newbury, C. E. Skinner.
Harold Pender,

*Ex-Officio*

Chairmen of Working Committees of Standards Committee
Chairmen of A. I. E. E. delegations on other standardizing bodies.

**EDISON MEDAL COMMITTEE**

*Appointed by the President for term of five years.*

(Term expires July 31, 1924)
E. D. Adams, Chairman, H. H. Barnes, Jr., B. G. Lamme.
(Term expires July 31, 1925)
H. M. Byllesby, D. E. Drake, W. L. R. Emmet.
(Term expires July 31, 1926)
B. A. Behrend, John H. Finney, C. S. Ruffner.
(Term expires July 31, 1927)
Gano Dunn, F. A. Scheffler, W. R. Whitney.
(Term expires July 31, 1928)
C. C. Chesney, Robert A. Millikan, M. I. Pupin.

*Elected by the Board of Directors from its own membership for term of two years.*

(Term expires July 31, 1924)
E. B. Craft, G. Faccioli, William McClellan.
(Term expires July 31, 1925)
H. M. Hobart, Frank B. Jewett, W. K. Vanderpoel.

*Ex-Officio*

Harris J. Ryan, President, George A. Hamilton, Treasurer, F. L. Hutchinson, Secretary.

**RESEARCH COMMITTEE**

John B. Whitehead, Chairman, Johns Hopkins University, Baltimore, Md.
Edward Bennett, C. I. Hall, L. F. Morehouse,
E. H. Colpitts, L. A. Hawkins, Harold Pender,
E. E. F. Creighton, V. Karapetoff, G. W. Pierce,
F. S. Dellenbaugh, Jr. A. E. Kennelly, Clayton H. Sharp,
W. A. Del Mar, M. G. Lloyd, C. E. Skinner,
W. P. Dobson, R. W. Sorensen.

## SPECIAL COMMITTEES

**COLUMBIA UNIVERSITY SCHOLARSHIP**

Francis Blossom, Chairman, 52 William Street, New York, N. Y.
F. B. Jewett, W. I. Slichter.

**AWARD OF INSTITUTE PRIZES**

L. W. W. Morrow, Chairman, *Electrical World*, 10th Ave. & 36th Street, New York, N. Y.
Chairmen of Technical Committees.

## TECHNICAL COMMITTEES

### EDUCATIONAL

W. E. Wickenden, Chairman, A. T. & T. Co., 195 Broadway, New York, N. Y.

W. C. Bauer, Edward Bennett, C. R. Dooley, Charles S. Howe, P. M. Lincoln, C. E. Magnusson, G. H. Pfeif, H. W. Price, Charles F. Scott, Harold B. Smith, W. L. Upson, John B. Whitehead, William R. Work.

### ELECTRICAL MACHINERY

H. M. Hobart, Chairman, General Electric Co., Schenectady, N. Y.

B. L. Barns, B. A. Behrend, R. E. Brown, James Burke, N. A. Carle, G. Faccioli, W. J. Foster, V. A. Fynn, David Hall, H. U. Hart, P. M. Lincoln, H. P. Liversidge, A. S. McAllister, F. D. Newbury, R. F. Schuchardt, Philip Torchio, R. B. Williamson.

### ELECTROCHEMISTRY AND ELECTROMETALLURGY

J. L. Yardley, Chairman, Westinghouse E. & M. Co., East Pittsburgh, Pa.

Carl Hering, J. A. Johnson, H. T. Plumb, J. A. Seede, G. W. Vinal, C. D. Woodward.

### ELECTROPHYSICS

F. W. Peek, Jr., Chairman, General Electric Co., Pittsfield, Mass.

E. F. Burton, L. W. Chubb, J. C. Clark, William Fondiller, Charles Fortescue, Roy S. Glasgow, Robert A. Millikan, J. H. Morecroft, Chester W. Rice, F. B. Silsbee, Harold B. Smith, J. B. Whitehead.

### INDUSTRIAL AND DOMESTIC POWER

H. D. James, Chairman, Westinghouse E. & M. Co., East Pittsburgh, Pa.

P. H. Adams, H. E. Bussey, S. F. Davies, C. W. Drake, T. D. Montgomery, H. W. Rogers.

### INSTRUMENTS AND MEASUREMENTS

G. A. Sawin, Chairman, Westinghouse E. & M. Co., East Pittsburgh, Pa.

P. A. Borden, H. B. Brooks, G. L. Crosby, F. P. Cox, E. D. Doyle, A. L. Ellis, H. Brightwell Johnson, Paul MacGahan, William M. McConahey, F. V. Magalhaes, Irving B. Smith, H. S. Vassar, Roy Wilkins.

### IRON AND STEEL INDUSTRY

F. B. Crosby, Chairman, Morgan Construction Co., 15 Belmont St., Worcester, Mass.

Gordon Fox, Eugene Friedlaender, E. S. Jefferies, D. M. Petty, A. G. Pierce, G. E. Stoltz, J. D. Wright.

### LIGHTING AND ILLUMINATION

G. H. Stickney, Chairman, Edison Lamp Works, G. E. Co., Harrison, N. J.

J. M. Bryant, W. Devereux, H. W. Eales, F. M. Feiker, F. F. Fowle, G. C. Hall, C. A. B. Halvorson, Jr., H. H. Higbie, A. S. McAllister, P. S. Millar, Charles F. Scott, B. E. Shackelford, W. M. Skiff.

### MARINE

G. A. Pierce, Chairman, Wm. Cramp & Sons S. & E. B. Co., Philadelphia, Pa.

J. B. Bassett, R. A. Beekman, L. C. Brooks, Maxwell W. Day, E. G. Gallagher, C. S. Gillette, H. Franklin Harvey, Jr., William Hetherington, Jr., H. L. Hibbard, John S. Isdale, William F. James, M. A. Libbey, C. S. McDowell, W. F. Meschenmoser, I. H. Osborne, H. M. Southgate, W. E. Thau, A. E. Waller.

### MINES

F. L. Stone, Chairman, General Electric Co., Schenectady, N. Y.

R. T. Andrae, C. N. Beebe, M. C. Benedict, Graham Bright, H. W. Eales, L. C. Ilsley, G. M. Kennedy, R. L. Kingsland, A. B. Kiser, D. C. McKeehan, W. F. Schwedes, W. A. Thomas, C. D. Woodward.

### POWER STATIONS

Nicholas Stahl, Chairman, Narragansett Electric Lighting Co., Turks Head Building, Providence, R. I.

H. A. Barre, J. T. Barron, E. T. Brandon, H. W. Eales, F. C. Hanker, John Harisberger, C. F. Hirshfeld, R. B. Howland, J. P. Jollyman, H. A. Kidder, W. H. Lawrence, H. P. Liversidge, D. C. McClure, I. E. Moultrop, C. P. Osborne, A. L. Penniman, Jr., F. A. Scheffler, R. F. Schuchardt, R. B. Williamson.

### PROTECTIVE DEVICES

H. R. Woodrow, Chairman, 360 Pearl Street, Brooklyn, N. Y.

G. H. Bragg, P. H. Chase, L. B. Chubbuck, Clarence T. Evans, F. C. Hanker, S. E. M. Henderson, E. A. Hester, F. L. Hunt, B. G. Jamieson, M. G. Lloyd, A. A. Meyer, W. H. Millan, N. L. Pollard, F. E. Ricketts, D. W. Roper, C. H. Sanderson, E. R. Stauffacher, E. C. Stone, A. H. Sweetnam, John B. Taylor.

### TELEGRAPHY AND TELEPHONY

O. B. Blackwell, Chairman, A. T. & T. Co., 195 Broadway, New York, N. Y.

F. L. Baer, H. P. Charlesworth, L. W. Chubb, E. H. Colpitts, R. N. Conwell, C. E. Davies, H. W. Drake, L. F. Fuller, D. H. Gage, P. J. Howe, F. H. Kroger, N. M. Lash, G. W. McRae, R. D. Parker, F. A. Raymond, Chester W. Rice, J. K. Roosevelt, Edgar Russel, H. A. Shepard, I. J. Thorp, F. A. Wolff, C. A. Wright.

### TRACTION AND TRANSPORTATION

N. W. Storer, Chairman, Westinghouse E. & M. Co., East Pittsburgh, Pa.

George Gibbs, Dugald C. Jackson, H. A. Johnson, W. S. Murray, W. B. Potter.

### TRANSMISSION AND DISTRIBUTION

F. G. Baum, Chairman, Hobart Building, San Francisco, Calif.

R. W. Atkinson, M. O. Bolser, Wallace S. Clark, W. H. Cole, R. N. Conwell, W. A. Del Mar, L. L. Elden, F. M. Farmer, J. P. Jollyman, L. M. Klauber, C. H. Kraft, W. S. Lee, W. M. McConahey, E. B. Meyer, G. J. Newton, F. W. Peek, Jr., A. M. Perry, G. G. Post, C. C. Robinson, D. W. Roper, C. E. Schwenger, Carroll H. Shaw, Arthur Simon, W. K. Vanderpoel, C. T. Wilkinson, R. J. C. Wood.

## A. I. E. E. Representatives

### ON AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, COUNCIL

A. E. Kennelly, John B. Taylor.

### ON AMERICAN BUREAU OF WELDING

H. M. Hobart.

### ON AMERICAN COMMITTEE ON ELECTROLYSIS

B. J. Arnold, N. A. Carle, F. N. Waterman.

### ON AMERICAN ENGINEERING COUNCIL OF THE FEDERATED AMERICAN ENGINEERING SOCIETIES

Comfort A. Adams, *C. G. Adsit, John H. Finney, F. L. Hutchinson, *Frank B. Jewett, W. A. Layman, *William McClellan, *L. F. Morehouse, L. T. Robinson, Charles S. Ruffner, *Charles F. Scott, C. E. Skinner, L. B. Stillwell, Calvert Townley.

*Members of Executive Board.

### ON AMERICAN ENGINEERING STANDARDS COMMITTEE

H. M. Hobart, Harold Pender, C. E. Skinner.
L. T. Robinson (Alternate)

### ON APPARATUS MAKERS AND USERS COMMITTEE

C. E. Skinner.

### ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY

H. H. Barnes, Jr. Bancroft Gherardi, H. A. Lardner.

### ON CHARLES A. COFFIN FELLOWSHIP AND RESEARCH FUND COMMITTEE

Frank B. Jewett.

### ON ENGINEERING FOUNDATION BOARD

Frank B. Jewett, E. W. Rice, Jr.

### ON INTERNATIONAL ENGINEERING CONGRESS, PHILADELPHIA 1926 BOARD OF MANAGEMENT

Gano Dunn, C. E. Skinner.

### ON JOHN FRITZ MEDAL BOARD OF AWARD

A. W. Berresford, John J. Carty, William McClellan, Frank B. Jewett.

### ON LIBRARY BOARD OF UNITED ENGINEERING SOCIETY

Edward D. Adams, E. B. Craft, F. L. Hutchinson, Alfred W. Kiddle, W. I. Slichter.

### ON NATIONAL FIRE PROTECTION ASSOCIATION, ELECTRICAL COMMITTEE

The Chairman of the Institute's Committee on Safety Codes

### ON NATIONAL RESEARCH COUNCIL, ENGINEERING DIVISION

C. A. Adams, Bancroft Gherardi, A. E. Kennelly.

### ON SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION, BOARD OF INVESTIGATION AND COORDINATION

Gano Dunn, Frank B. Jewett.

### ON U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ILLUMINATION COMMISSION

A. E. Kennelly, C. O. Mailloux, Clayton H. Sharp.

### ON WASHINGTON AWARD, COMMISSION OF

John Price Jackson, Charles F. Scott.

### ON U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ELECTROTECHNICAL COMMISSION

C. O. Mailloux, President, 111 Fifth Ave., New York, N. Y.
D. C. Jackson, Vice-President,
[1]James Burke, Vice-President,
C. H. Sharp, Secretary, 556 E. 80th St., New York.

C. A. Adams, P. G. Agnew, [8]C. A. Bates, B. A. Behrend, [8]A. W. Berresford, J. J. Carty, L. W. Chubb, [8]Le Roy Clark, [1]C. L. Collens, 2d, W. A. Del Mar, [1]A. L. Doremus, Gano Dunn, [6]L. L. Elden, W. C. Fish, H. W. Fisher, [6]Gen. G. H. Harries, H. M. Hobart, A. E. Kennelly, B. G. Lamme, [5]R. A. Lundquist, A. S. McAllister, [4]Com. C. S. McDowell, [7]J. Franklin Meyer, W. S. Moody, A. H. Moore, R. W. E. Moore, L. F. Morehouse, Harold Pender, [6]S. G. Rhodes, Charles Robbins, L. T. Robinson, D. B. Rushmore, [8]H. R. Sargent, C. F. Scott, C. E. Skinner, [3]Gen. George O. Squier, Elihu Thomson, [1]A. E. Waller, [2]C. L. Warwick, R. B. Williamson.

[1]Representative of Electric Power Club.
[2]Representative of American Society for Testing Materials.
[3]Representative of War Department.
[4]Representative of Navy Department.
[5]Representative of Bureau of Foreign and Domestic Commerce.
[6]Representative of National Electric Light Association.
[7]Representative of Bureau of Standards.
[8]Representative of Associated Manufacturers of Electrical Supplies.

## LIST OF SECTIONS

| Name | Chairman | Secretary |
|---|---|---|
| Akron | P. C. Jones | C. D. Black, B. F. Goodrich Co., Akron, Ohio |
| Atlanta | G. K. Selden | H. N. Pye, Box 1743, Atlanta, Ga. |
| Baltimore | W. B. Kouwenhoven | R. T. Greer, Lexington Building, Baltimore, Md. |
| Boston | Alex. Macomber | Ira M. Cushing, 39 Boylston St., Boston, Mass. |
| Chicago | J. E. Kearns | George H. Jones, 72 W. Adams St., Chicago, Ill. |
| Cincinnati | A. M. Wilson | C. G. Eichelberger, Union Gas & Elec. Co., Cincinnati, O. |
| Cleveland | G. B. Schneeberger | T. D. Owens, Case School of Applied Science, Cleveland, O. |
| Columbus | E. M. Fitz | A. W. Janowitz, 303 Hartman Building, Columbus, O. |
| Connecticut | E. H. Everit | A. E. Knowlton, Dunham Laboratory, Yale University, New Haven, Conn. |
| Denver | H. B. Dwight | R. B. Bonney, 603 Wyoming Building, Denver, Colo. |
| Detroit-Ann Arbor | E. L. Bailey | F. L. Snyder, 1365 Cass Ave., Detroit, Mich. |
| Erie | M. W. Metzner | L. H. Curtis, General Electric Co., Erie, Pa. |
| Fort Wayne | C. C. Grandy | L. C. Yapp, General Electric Co., Ft. Wayne, Ind. |
| Indianapolis-Lafayette | D. C. Pyke | J. W. Hannon, Telephone Building, Indianapolis, Ind. |
| Ithaca | J. G. Pertsch, Jr. | Geo. F. Bason, Cornell University, Ithaca, N. Y. |
| Kansas City | Geo. C. Shaad | W. E. A. Nottorf, Kansas City Tel. Co., Kansas City, Mo. |
| Lehigh Valley | H. G. Harvey | G. W. Brooks, Penna. Power & Light Co., Allentown, Pa. |
| Los Angeles | J. N. Kelman | E. R. Stauffacher, 700 Edison Building, Los Angeles, Calif. |
| Lynn | L. E. Smith | P. E. Twiss, General Electric Co., West Lynn Works, West Lynn, Mass. |
| Madison | G. E. Wagner | R. G. Walter, 900 Gay Building, Madison, Wis. |
| Mexico | D. K. Lewis | E. F. Lopez, Westinghouse Elec. Int'l. Co., Apartado, No. 78-Bis., Mexico City, Mexico. |
| Milwaukee | S. H. Mortensen | H. L. Smith, Louis Allis Co., 133 Stewart St., Milwaukee, Wis. |
| Minnesota | H. W. Meyer | N. W. Kingsley, N. W. Bell Telephone Co., Minneapolis, Minn. |
| New York | L. F. Morehouse | E. B. Meyer, 80 Park Place, Newark, N. J. |
| Oklahoma | W. J. Miller | A. D. Stoddard, Box 382, Bartlesville, Okla. |
| Panama | F. B. Coyle | M. P. Benninger, Box 174, Balboa Heights, C. Z. |
| Philadelphia | R. B. Mateer | R. H. Silbert, Philadelphia Elec. Co., 2301 Market St., Philadelphia, Pa. |
| Pittsburgh | O. Needham | M. E. Skinner, Duquesne Light Co., Pittsburgh, Pa. |
| Pittsfield | E. D. Treanor | J. R. Rue, General Electric Co., Pittsfield, Mass. |
| Portland, Ore. | E. F. Pearson | H. P. Cramer, Portland Ry. Lt. & Pr. Co., Electric Bldg., Portland, Ore. |
| Providence | H. A. Stanley | F. N. Tompkins, Brown University, Providence, R. I. |
| Rochester | W. S. Burch | Elmer E. Strong, 523 Commerce Building, Rochester, N. Y. |
| St. Louis | J. M. Chandlee | Lee S. Washington, 717 S. 12th St., St. Louis, Mo. |
| San Francisco | J. A. Koontz, Jr. | A. G. Jones, 807 Rialto Building, San Francisco, Calif. |
| Schenectady | R. C. Muir | C. M. Cogan, Lighting Engg. Dept., General Electric Co., Schenectady, N. Y. |
| Seattle | C. A. Lund | J. Hellenthal, 606 Electric Bldg., Seattle, Wash. |
| Southern Virginia | Wm. C. Bell | Harold C. Leonard, P. O. Box 1194, Richmond, Va. |
| Spokane | E. R. Hannibal | James S. McNair, Washington Water Power Co., Spokane, Wash. |
| Springfield, Mass. | W. A. Dick | J. Frank Murray, United Elec. Lt. Co., Springfield, Mass. |
| Syracuse | R. D. Whitney | Walter C. Pearce, 421 S. Warren St., Syracuse, N. Y. |
| Toledo | Gilbert Southern | Max Neuber, 1257 Fernwood Ave., Toledo, O. |
| Toronto | C. E. Schwenger | D. B. Fleming, Hydro Elec. Power Commission, 190 University Ave., Toronto, Ont. |
| Urbana | E. B. Paine | Charles T. Knipp, University of Illinois, Urbana, Ill. |
| Utah | C. R. Higson | Hiram W. Clark, 400 C. & C. Bldg., Salt Lake City, Utah |
| Vancouver | F. W. MacNeill | A. Vilstrup, B. C. Electric Railway Co., 425 Carroll St., Vancouver, B. C. |
| Washington, D. C. | L. M. Evans | A. F. E. Horn, Commercial National Bank Bldg., Washington, D. C. |
| Worcester | L. E. Pierce | Stuart M. Anson, 1005 Park Bldg., Worcester, Mass. |

Total 47

## LIST OF BRANCHES

| Name and Location | Chairman | Secretary |
|---|---|---|
| Alabama Poly. Inst., Auburn, Ala. | K. H. Stough | J. F. Nettles |
| Alabama, Univ. of, University, Ala. | M. S. Merritt | J. A. Zobel |
| Arizona, Univ. of, Tucson, Ariz. | Roy Osborne | Paul Sawyer |
| Arkansas, Univ. of, Fayetteville, Ark. | Joe Cunningham | C. E. Bowman |
| Armour Inst. of Tech., Chicago, Ill. | D. E. Richardson | J. S. Farrell |
| Brooklyn Poly. Inst., Brooklyn, N. Y. | H. B. Hanstein | J. E. Loerch |
| Bucknell Univ., Lewisburg, Pa. | W. G. Gehring | E. S. Hopler |
| California Inst. of Tech., Pasadena | Harold Preston | C. A. Storms |
| California, Univ. of, Berkeley, Calif. | J. A. Holden | |
| Carnegie Inst. of Tech., Pittsburgh, Pa. | W. J. Lyman | R. A. Garbett |
| Case School of Applied Science, Cleveland, O. | M. S. Mead | A. S. Campbell |
| Cincinnati, Univ. of, Cincinnati, O. | W. F. Dunkl | C. B. Hoffman |
| Clarkson Coll. of Tech., Potsdam, N. Y. | C. E. Tuiter | H. C. Allen |
| Clemson Agri. College, Clemson College, S. C. | R. W. Pugh | O. A. Roberts |
| Colorado State Agri. Coll., Ft. Collins | Floyd Hall | W. M. Truesdell |
| Colorado, Univ. of, Boulder, Colo. | M. B. Inman | C. V. Roberts |
| Cooper Union, New York | G. E. Wilson | H. E. Thompson |
| Denver, Univ. of, Denver, Colo. | L. W. Thomson | Ray Hoover |
| Drexel Institute, Philadelphia, Pa. | D. Buchanan | R. E. Sidwell |
| Georgia School of Tech., Atlanta, Ga. | J. L. Torbett | F. R. McClellan |
| Iowa State College, Ames, Iowa | A. Paone | R. E. Paxton |
| Iowa, Univ. of, Iowa City, Iowa | C. W. Peterson | M. Bushby |
| Kansas State College, Manhattan | V. O. Clements | W. K. Lockhart |
| Kansas, Univ. of, Lawrence, Kans. | D. Eyer | W. Anderson |
| Kentucky, Univ. of, Lexington, Ky. | T. M. Riley | H. D. Broilsford |
| Lafayette College, Easton, Pa. | K. A. F. Pitt | L. Conover |
| Lehigh Univ., S. Bethlehem, Pa. | E. W. Baker | D. C. Luce |
| Lewis Institute, Chicago, Ill. | E. Millison | C. P. Meek |
| Maine, Univ. of, Orono, Me. | C. R. Lappin | H. L. Durgin |
| Marquette Univ., Milwaukee, Wis. | E. O. Triggs | N. W. Hoffman |
| Massachusetts Inst. of Tech., Cambridge, Mass. | E. J. Thimmie | H. D. McKinnon |
| Michigan Agri. Coll., East Lansing | S. N. Galbraith | V. O. Bernthal |
| Michigan, Univ. of, Ann Arbor, Mich. | C. C. Farnum | K. W. Richards |
| Milwaukee, Engg. School of, Milwaukee, Wis. | M. J. Maiers | J. P. Gibbons |
| Minnesota, Univ. of, Minneapolis | L. McLeland | Fred Kapple |
| Missouri, Univ. of, Columbia, Mo. | M. P. Weinbach | D. C. Jackson, Jr. |
| Montana State Coll., Bozeman, Mont. | R. R. Thomas | J. A. Thaler |
| Nesbraska, Univ. of, Lincoln, Neb. | O. J. Ferguson | O. E. Edison |
| North Carolina State College, Raleigh, N. C. | Z. M. Harry | P. M. Sullivan |
| North Carolina, Univ. of, Chapel Hill | L. P. Brown | H.C.Klingenschmitt |
| North Dakota, Univ. of, University | C. W. Randall | Byron Hill |
| Northeastern Univ., Boston, Mass. | B. F. Keene | L. F. Hubby |
| Notre Dame, Univ. of, Notre Dame, Ind. | V. J. Brown | W. L. Shilts |
| Ohio Northern Univ., Ada, Ohio | I. Weaver | A. D. Beck |
| Ohio State Univ., Columbus, O. | L. S. C. Neeb | J. M. Comly |
| Oklahoma A. & M. Coll., Stillwater | I. T. Knight | L. C. Minnich |
| Oklahoma, Univ. of, Norman, Okla. | J. A. Diffendoffer | M. F. Hill |
| Oregon Agri. Coll., Corvallis, Ore. | M. P. Bailey | E. E. Bricker |
| Pennsylvania State College, State College, Pa. | H. T. Axford | D. N. Yoder |
| Pennsylvania, Univ. of, Philadelphia | G. V. Cresson | O. Ortlieb |
| Pittsburgh, Univ. of, Pittsburgh, Pa. | L. L. Hughes | G. K. Walton |
| Purdue Univ., Lafayette, Ind. | E. T. Oberchain | L. R. Bridge |
| Rensselaer Poly. Inst., Troy, N. Y. | F. M. Sebast | R. Paxton |
| Rose Poly. Inst., Terre Haute, Ind. | D. V. Eichen | R. B. Bennett |
| Rutgers College, New Brunswick, N. J. | E. G. Riley | E. J. Butler |
| Southern California, Univ. of, Los Angeles, Calif. | K. C. Mobary | W. G. Angermann |
| Stanford Univ., Stanford University, Calif. | H. Bumbaugh | G. R. Stray |
| Swarthmore Coll., Swarthmore, Pa. | N. Landis | J. H. Thompson, Jr. |
| Syracuse Univ., Syracuse, N. Y. | L. E. Angwin | L. E. Lawrence |
| Texas A. & M. Coll., College Station | H. C. Hultgren | H. M. Stewart |
| Texas, Univ. of, Austin, Tex. | C. R. Granberry | C. H. Linder |
| Virginia Military Inst., Lexington | J. Girand | J. E. Woodward |
| Virginia Poly. Inst., Blacksburg, Va. | T. F. Cofer | F. L. McClung |
| Virginia, Univ. of, University, Va. | T. R. Bunting | J. W. McNair |
| Washington, State Coll. of, Pullman | C. R. Studer | E. J. Leahy |
| Washington Univ., St. Louis, Mo. | A. B. Newell | H. J. Schwenk |
| Washington, Univ. of, Seattle, Wash. | E. Kraft | E. T. Naden |
| West Virginia Univ., Morgantown | W. D. Stump | C. Snyder |
| Wisconsin, Univ. of, Madison, Wis. | E. J. Thomas | G. E. Bean |
| Yale Univ., New Haven, Conn. | J. T. Houk | G. L. Artamonoff |

Total 70

# DIGEST OF CURRENT INDUSTRIAL NEWS

## NEW CATALOGUES AND OTHER PUBLICATIONS

**Motors.**—Bulletin 1087-D, 16 pp. Describes large polyphase induction motors. Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

**Charging Equipment.**—Bulletin 51, 12 pp. Describes battery charging motor generators for trucks, tractors and locomotives. Electric Products Company, Cleveland, Ohio.

**Motors.**—Bulletin 5018, 16 pp. Describes Type AA induction motors for two and three-phase alternating circuits. Reliance Electric & Engineering Company, Cleveland, O.

**Wiring Devices.**—1923 Catalog, 160 pp. Describes a complete line of wiring devices, gives prices, standard package quantities, shipping rates, etc. The Arrow Electric Company, Hartford, Conn.

**Boiler Damper Control**.—Bulletin, 12 pp. Describes the Northwestern boiler damper control for use with underfeed stokers employing forced draft or with gas or oil fired boilers. Northwestern Manufacturing Company, Milwaukee, Wis.

**Instruments for Radio Control Panels.**—Bulletin 10, 8 pp. Describes small size direct and alternating current ammeters and voltmeters, including thermo-ammeters for antenna circuits, for use in radio sets. Roller-Smith Company, 12 Park Place, New York.

**Battery Charging Equipment.**—Bulletin 43976, 12 pp. Describes charging equipment for vehicle motive power batteries. General Electric Company, Schenectady, N. Y.

**Insulators.**—Catalog describing high tension porcelain insulators; also Bulletin 5 giving electrical and mechanical characteristics of flange type insulators for switching equipment, bus supports, etc. Jeffery-DeWitt Insulator Company, 50 Church Street, New York.

**Polyphase Transformers.**—Bulletins 2021 and 2022, each 4 pp. Describe the advantages in general of polyphase transformers, and outline the design and construction of the new Pittsburgh polyphase transformer. Pittsburgh Transformer Company, Pittsburgh, Penn.

**Circuit Breakers.**—Advance Bulletin 445-2, 4 pp. Describes Type D-17-A and Type D-17-B oil circuit breakers and oil switches with manual and electrical remote control, automatic or non-automatic. Condit Electrical Manufacturing Company, South Boston, Mass.

**Transformers.**—"Installation and Care of Transformers" is the subject of a new booklet, 16 pp. issued by the Packard Electric Company, Warren, Ohio. Load value cards intended as a guide for the proper fusing of transformers are also being distributed.

**Theft-proof Bulb.**—Bulletin describes a new theft-proof electric bulb which fits into any standard socket, is used the same as any ordinary lamp and is to be marketed at standard lamp prices. Lester Culp, 143 West Austin Avenue, Chicago, Ill.

**Lightmeter.**—Bulletin 343-A. 12 pp., describing the "Holophane Lightmeter," a portable instrument designed for the measurement of foot candles, lamberts, candles per square inch, candle power, coefficients of reflection, transmission factors and for color matching. Holophane Glass Company, 342 Madison Avenue, New York.

**Insulators.**—Catalog 100, 12 pp. Outlines the advantages of "Paramold," a molded composition for insulating purposes, such as transformer bushings, bus supports, disconnecting switches and similar devices used in the distribution of electrical energy at high potential. Illustrations of such applications as well as for terminal blocks, test blocks, etc., are included. Hopewell Insulation & Manufacturing Company, Hopewell, Va.

**Street Lighting.**—The Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., has issued two new catalogs on electric lighting equipment: Catalog 8-A on Overhead Street Lighting Equipment; and Catalog 8-B on Ornamental Street Lighting. The first catalogue contains 72 pages and the second 68, and both are illustrated with photographs and line drawings. In addition to the lighting equipment itself, the catalogues contain a complete descriptive list of accessories such as cables, potheads, mast arms, cut-out pulleys, etc.

**Relays.**—Bulletin 47635, 8 pp. Describes Type PQ-25 and Type PQ-26 under-voltage relays, which provide protection of apparatus from damage caused by sudden return of supply voltage after its failure or reduction. These relays are used for tripping electrically operated circuit breakers when the voltage has decreased to a certain predetermined value; for automatically disconnecting motors on under-voltage, and in any case where it is desirable to operate an auxiliary circuit on the occurrence of a decrease in voltage. General Electric Company, Schenectady, New York.

**Air Filters.**—Bulletin, 48 pp. Describes in a comprehensive manner a system of air filtration for electrical apparatus and in industrial processes. Illustrates the construction and operation of "Midwest Air Filters," which consist of units, each a shallow steel box having perforated sheet metal covers in front and rear and filled with filter materials. All surfaces exposed to the passing air are covered with a thin film of non-evaporating fluid, to which the incoming dust adheres. Almost 100% efficiency is claimed for this type of filter. Midwest Air Filters, Inc., 100 East 45th Street, New York.

## NOTES OF THE INDUSTRY

**The Irvington Varnish & Insulator Company, Irvington, N. J.,** has taken over the selling agency of the output of the Harvey Wire Company, of Newark, N. J., manufacturers of enameled, silk covered and cotton covered wire, and will supply the electrical industry with these products.

**Uehling Instrument Co., Paterson, N. J.,** combustion engineers and manufacturers of steam power plant economy apparatus, including $CO_2$ recorders, have appointed three new Southern representatives, namely Connor-Hudson Co., Southwestern Life Bldg., Dallas, Texas; Gibbens and Gordon Inc., 532 Canal Street, New Orleans, La.; and the Cornell Mathews Co., 10 Oak St., Orlando, Fla.

**Thirty-Year Review of General Electric Company.**—A review of the history of the General Electric Company from its foundation in 1892, to 1922, is made the subject of an interesting 34-page booklet issued to the company's stockholders. It traces the development of the electrical art and the astonishing growth of the electrical industry. Chapters are included on "Large Scale Power Generation," "Contributions to Long Distance Wireless Communication," "Progress in Illumination," "How G-E Money is Spent" and others. Under the final chapter "Opportunities for the Future" it says "........when it is considered that only 55 per cent of the manufacturing establishments and mines in the United States are operated by electricity, and that but 38 per cent of the people of the United States are living in electrically lighted homes, and that only a still smaller proportion are using electrical appliances, it will be seen that the future promises for this great industry even larger growth and expansion than has yet been realized......"